STM JOURNALS

Trends in
Drug Delivery

ISSN: 2394-7268
Volume 11, Issue 3, 2024
September–December
DOI (Journal): 10.37591/TDD

https://journals.stmjournals.com/tdd

Review TDD

Recent Advances & Prospects of Transferosomes for Transdermal Delivery: Trends in Drug Delivery

Sakshi Chauhan[1], Moumita Barman[2,*], Monika Singh[3]

Abstract

There have been several non-invasive administrations that have emerged recently to replace conventional needle injections. With its minimal rejection rate, remarkable ease of administration, and remarkable patient comfort and perseverance, the transdermal drug delivery system (TDDS) is the most attractive of them all. The skincare industry, which includes cosmetics, may also find use for TDDS in addition to the pharmaceutical industry. As this strategy mainly entails local drug administration, it can prevent untargeted drug delivery to tissues not intended for the treatment and buildup of localized drug concentrations. Transdermal delivery is hampered by several physicochemical characteristics of the skin, which have led to a great deal of research into ways to get over these barriers. Most transdermal medicines that have proved effective, do so by using smaller lipophilic compounds, which have a molecular weight of a few 100 Daltons. Transferosomes have proven to be an effective method for transdermal distribution of a range of therapies, including hydrophilic actives, bigger molecules, peptides, proteins, and nucleic acids, to get around the medications' size and lipophilicity limits. Because of their flexible form and increased surface hydrophilicity, transferosomes are essential for the delivery of medicines and other solutes through and into the skin by exploiting hydration gradients a source of energy. As a result, the medication is released into the skin layers under regulated conditions and has improved overall penetration. This review outlines the development of transferosomes from liposomes and solid lipid nanoparticles, as well as their subsequent advancements as commercially available dosage forms, physical-chemical characteristics, and cutaneous kinetics.

Keywords: Transdermal delivery, transdermal drug delivery system (TDDS), transferosomes, nanoparticles, stratum corneum

INTRODUCTION

The worldwide burden of ailments programmes, rank skin illnesses as the fourth most common source of nonfatal disease burden; dermatitis contributes the most to this burden, while cellulitis contributes the least. Acne ranked second globally in terms of skin disease burden out of 19, 727 papers on the subject published throughout 2015 and 2020, yet it only made up 2.42% of all publications in the literature [1, 2]. This suggests that more focused scientific study on skin disorders is necessary. Furthermore, despite recent technical breakthroughs, some dermatoses, such as severe atopic dermatitis, have restricted therapy choices due to biological barriers, related systemic side effects, and limits in product composition, including medication solubility [3–5].

The skin makes up around 16% of the total weight of an adult, making it the biggest organ in

***Author for Correspondence**
Moumita Barman
E-mail: moumitab297@gmail.com

[1]PG Scholar, Department of Pharmacy Practice, Srinivas College of Pharmacy, Valachil, Farangipete Post, Mangalore, Karnataka, India
[2]Associate Professor, Department of Pharmacology, Srinivas College of Pharmacy, Valachil, Farangipete Post, Mangalore, Karnataka, India
[3]Professor, Department of Pharmaceutics, Srinivas College of Pharmacy, Valachil, Farangipete Post, Mangalore, Karnataka, India

Received Date: September 23, 2024
Accepted Date: October 01, 2024
Published Date: October 26, 2024

Citation: Sakshi Chauhan, Moumita Barman, Monika Singh. Recent Advances & Prospects of Transferosomes for Transdermal Delivery: Trends in Drug Delivery: 2024; 11(3): 1–21p.

the human body. As a result, it contributes significantly to homeostasis maintenance and serves as a biological, chemical, and physical barrier against external environmental hazards. The shortcomings and limitations of traditional applied topically and transdermal formulations, including ointments and creams, which are comparatively effective in managing several dermatological diseases, emphasize the evolution and progress of technologies to improve drug penetration and delivery [6–8]. These formulations also have limited bioavailability and targeted drug delivery. Due to this, innovative topical and transdermal drug delivery methods had to be created (Figure 1). Examples of these include nano-based technologies, which greatly enhance dermatotherapy and solve some of the formulation issues, such as drug solubility in addition to avoiding various issues related to the administration of drugs orally later, such as the hepatic first-pass impact, higher dosage frequency ranges, and compliance from patients [9, 10].

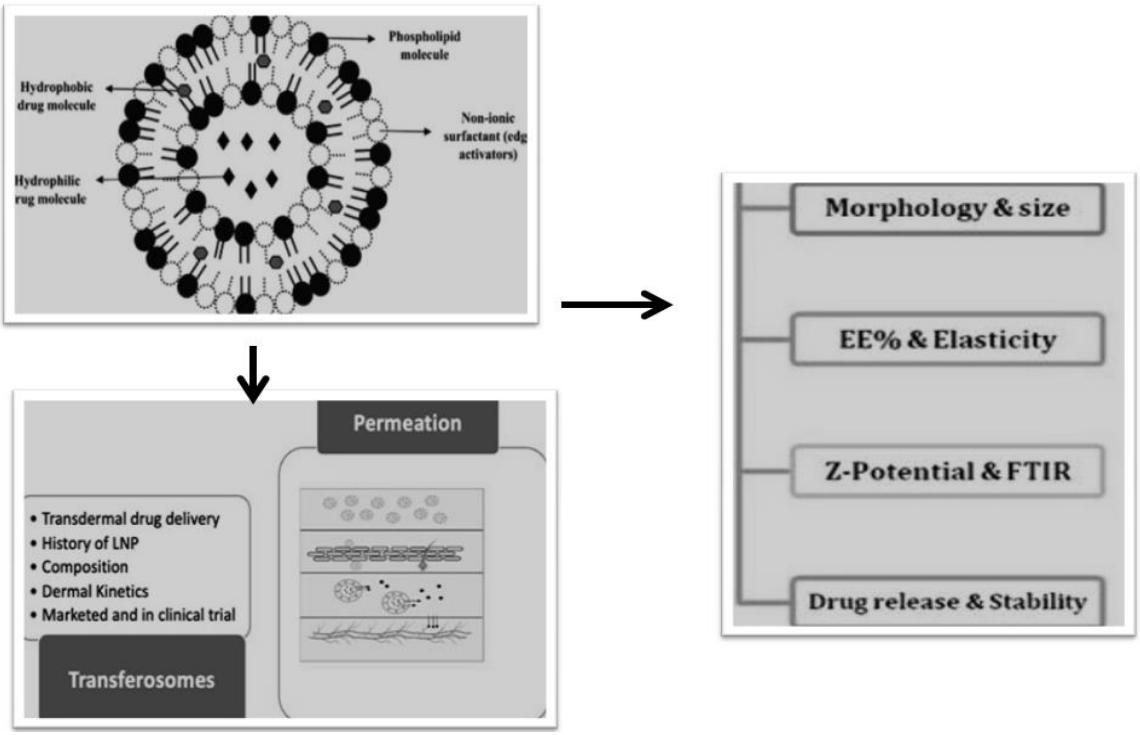

Figure 1. Mechanism of Transfersomes.

Dermatologists and pharmaceutical researchers have focused a great deal on the creation and emergence of multiple nanocarriers used in delivery methods, both topical and transdermal because of their many advantages. Their unique physicochemical characteristics have shown their overall greater therapeutic effectiveness in delivering focused drug release that is both efficient and sustained. The four main categories of nanocarriers include polymeric, vesicular (liposomes, ethosomes, niosomes, transferosomes and transethosomes), lipid-based (liposomes, nanostructured lipid carriers, and solid-lipid nanoparticles), and metallic (Table 1) [16, 17]. The categorization includes nanoemulsions, nanofibers, and microneedles. Several recently established nano-formulations contain certain elements, including cosurfactants and surfactants, which serve as contributing factors of penetration and have the capability to customise and change the cellular and dynamic membranes structure by loosening the tightly bound connections between skin layers and create short-term pores [18].

These molecular changes result in the changeable remodeling of skin's barrier, which improves the capability of treatments to pass through the skin barrier and enter the skin's deeper layer through nanocarriers. Although transdermal and topical technologies have advanced significantly, this mini-review focused mostly on developments in the field of nanotechnology, providing a quick overview of some of the emerging and present methods and technologies targeted at enhancing transdermal distribution [19–21].

Table 1. Based on Pulsipher et al., 2021, the ranks and representation of skin diseases in literature worldwide between 2015 and 2020 are licenced under the Creative Commons BY-NC-ND licence (http://creativecommons.org/licenses/BY-NC-ND/4.0/) [11–15].

Skin Diseases	Global Burden of Skin Disease Rank	Rank by Total Percentage of Publications	Percentage of Global Burden
Dermatitis	1	3	0.38
Acne	2	4	0.29
Psoriasis	3	2	0.19
Urticaria	4	7	0.19
Viral skin diseases	5	5	0.16
Fungal skin diseases	6	6	0.15
Scabies	7	10	0.07
Melanoma	8	1	0.06
Pyroderma	9	8	0.05
Cellulitis	10	9	0.04

The Barrier Function of the Skin

A brief examination of the skin as a barrier is required to help grasp the key ideas behind the creation of the new technologies, even if the objective of this project is to offer knowledge of the latest developments and techniques in delivery of drugs via topical and transdermal methods. The five layers that comprise the epidermis, or outermost layer of the skin, are the stratum spinosum, stratum lucidum, stratum granulosum, stratum corneum (SC), and stratum basale (Figure 2).

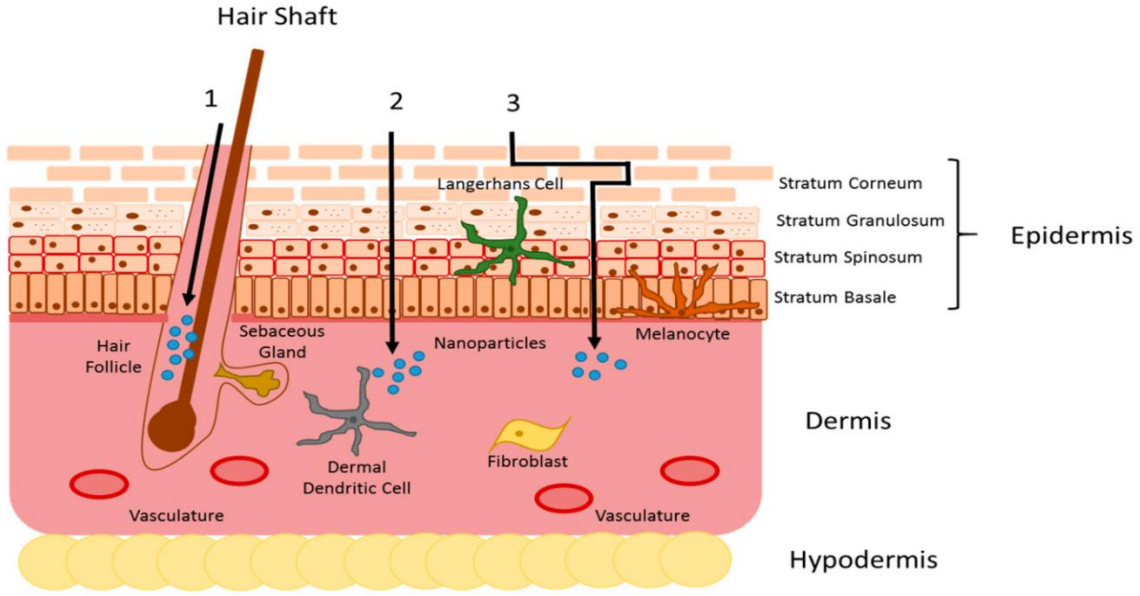

Figure 2. Routes of administration through skin [30].

The uppermost layer, known as the stratum corneum, has a surface area of around 2 m^2. The SC, which is thought to be the rate-limiting stage in absorption process via the skin, is a dense keratinocyte matrix that has reached terminal development, scattered among lipids that is around 10 µm thick [22–24]. Big molecules and hydrophilic molecules are both blocked by a sound and functional SC. Only substances having a molecular weight of as much as 500 Da can be delivered transdermally due to the SC's resistance to molecular diffusion. Furthermore, the situation and state of the skin may have a complete bearing on the drug candidate's ability to penetrate the skin barrier [25–27]. The SC surrounds the living epidermis, that is made up of many layers of skin formed of living

keratinocytes. The dermal layer is made up of fibroblasts, connective tissues (elastin and collagen), as well as extracellular elements including glands and hair follicles. For the management of skin-related illness, sophisticated nanotechnology-derived nanocarriers can penetrate the epidermis and approach target locations [28]. By boosting the drug's skin-partitioning and solubility, these nanocarriers help to pass through the barrier of stratum corneum and enable the administration of the prescribed dosage to the intended location. The goals of this review restrict the discussion of percutaneous absorption, despite its importance in drug delivery via topical and transdermal methods; nevertheless, Roberts et al. and Benson et al. offer thorough and up-to-date reviews on the development, historical background, and recent advancements in transdermal absorption [29, 30].

TRANSFEROSOMES

The recently introduced unique drug carriers transferosomes, sometimes referred as transfersomes, are extremely malleable vesicles that can move big molecules across intact mammalian skin. In its most comprehensive form, a transfersome is a tool that enters the skin organically for delivery of drugs from the place of application to the intended site [31, 32]. This year, despite being more widely discussed, the practical application of lipid vesicles as a means of drug administration for skin therapy is still disputed; relevant papers primarily emphasize the impact of liposome localization, with a few cases further detailing the transport procedures as well, dependent upon the formulation (Figure 3) [33].

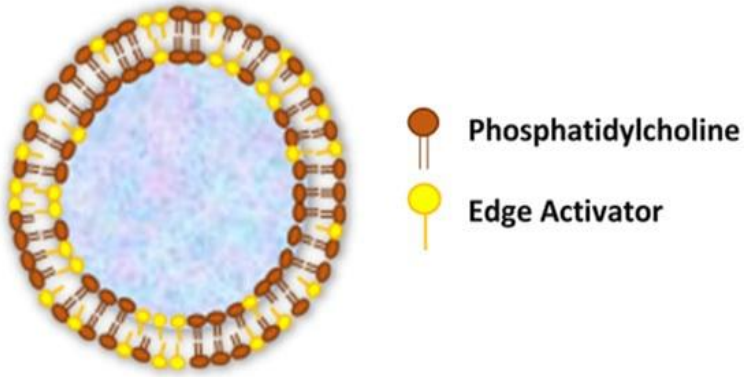

Figure 3. Schematic diagram of transferosomes [34].

A novel class of extremely flexible lipid vesicles known as transfersomes, which may be applied non-occlusively and penetrate intact skin, may provide a solution to these issues. This is because transepidermal osmotic gradients, which drive elastic transport into the skin, require non-occlusive conditions to be created [35]. The differential in water concentration among the inside and outside of the skin is what causes the osmotic gradient. Transfersomes have a high degree of deformability, which helps them enter the subcutaneous tissue's intercellular lipid route quickly [36, 37]. Based on some initial investigations, there are violations in the lipid packing between cells of mouse subcutaneous tissue, which serves as an online platform for transfersome permeation. Based on definitions, transfersomes are specially designed vesicular particles enclosed by lipid vesicles and containing at least one internal aqueous compartment. Although they resemble liposomes morphologically, transfersomes are operationally sufficiently pliable to fit through openings that are considerably smaller than themselves [38–40].

History of Transfersomes

The name "transfersome", originally used by Cevc, refers to the initial generation of ultra deformable vesicles which is now the topic of multiple scholarly articles and patents ever since the 1990s (Transfersomes, a Munich, Germany-based IDEA AG trademark). These elastic vesicles' ability to penetrate and permeate skin is the result of their carrier qualities and access enrichment capacity interacting in a synergistic way [41]. Transfersomes, which are composed of at least one lipid

bilayer-enclosed inner aqueous section with adjusted characteristics suitable for the existence of surface-active agents in the vesicular membrane (edge activator (EA)), are supramolecular aggregates in lipid bundles that are ultradeformable. It is widely acknowledged that liposomes can only penetrate the stratum corneum's outermost layer, which restricts their capacity to localise cosmetics or medications under the skin. However, transfersomes possess the capacity to circulate unchanged vesicles across the skin's layers and make their way to the whole circulation [42, 43]. The non-steroidal anti-inflammatory drug (NSAID) ketoprofen was a commercial success and demonstrated efficacy in terms of validation. In 2007, the regulatory body Swiss Medic authorized the use of ketoprofen under the trade name "Ketoprofen transdermal", which was manufactured by "IDEA AG" Pharmaceuticals Pvt. Ltd. [44, 45].

Composition of Transfersomes

According to some reports, transferosomes can travel across channels in the stratum corneum that have diameters smaller than tenth of the circumference of the transferosome because the molecules of surfactants act as "edge activators" and offer the transferosomes extreme malleability. Transferosomes that are larger than 500 nm may spontaneously navigate through pores less than 50 nm in size, when liposomes have become too big to do so. As a result, the stratum corneum barrier can be crossed by the transferosomes. They suggest that the "transdermal gradient", which is the outcome of variation in the amount of water occurs between the relatively dry skin surface (approximately 20% water) and the nearly 100% watery viable epidermis, which is what drives penetration through the skin [46, 47].

The proper amount of surface-active material can be added to transferosomes to make them malleable. When forming transferosomes, the concentration of an active surface ingredient is necessary because, these substances cause vesicle membranes to become flexible at sublytic doses and to break down completely at higher concentrations. The flexibility of transferosomal membranes allows highly deformable transferosomes to alter their membrane composition both locally and reversibly when they are pushed up against or drawn into a small pore. which also reduces the possibility of a total vesicle breach in the skin [48]. This leads to a notable decrease in the energy required for membrane deformity and enable the incredibly malleable nanoparticles to pass through and depart the pores with remarkable effectiveness [49].

The carrier aggregation is made up of a minimum of one amphipath (such as phosphatidylcholine), which in an aqueous solvent forms a lipid bilayer by itself and then becomes a simple lipid vesicle upon condensation [50]. There is a notable increase in lipid bilayer penetration and flexibility by the inclusion of a minimal of one bilayer softening component (including variables such as a biocompatible surfactant or an amphiphilic drug). The transferosome vesicles may swiftly and easily adapt to the shape of their surroundings by enhancing the subsequent permeability and flexibility. Thus, they could potentially alter the regional amount of each bilayer component under the localized tension of the bilayer [51]. The basic structure of these vesicles is largely like that of liposomes. However, the primary distinction between these transferosomes and conventional vesicles is their artificial membrane. which is softer, more flexible, and more adaptable [52].

The capability of transferosomes to bind and retain water is also increased by greater bilayer deformability, which is beneficial. In an ongoing effort to avoid dehydration, a very hydrophilic and ultradeformable vesicle may use a transport process like but different from forward osmosis [53]. To ensure adequate hydration, a transferosome vesicle placed on a biological surface that is visible, with the value non-occluded skin, will usually cross its barrier and go into the deeper, more aqueous layers. For barrier penetration, reversible bilayer deformation is needed, but for the underpinning hydration affinity and gradients to stay in location, neither the vesicle integrity nor the barrier properties can be significantly put at risk [54]. The transferosome needs to determine and enforce its own route through the organ since it is too big for diffusion throughout the skin. Thus, the carrier's capacity to penetrate and enlarge the hydrophilic channels in the dermis or another barrier is necessary to employ transferosomes in the administration of drug. The following progressive agent release by the drug's

carrier allows the drug molecules to scatter and eventually adhere to their target [55]. A lipid bilayer fusion between the cell membrane and the carrier may also occur during the delivery of a drug to an intracellular activation site, provided the vesicle is deliberately taken up within the cell in a process known as endocytosis [56, 57].

METHOD OF PREPARATION

Method of Rotary Film Evaporation

Bangham is credited with creating the hand-shaking procedure, another name for this technique. The number of phospholipids and surfactants (as EAs) required for this process is crucial for the organisation of a thin film. Wearing it is mostly done for multilamellar vesicle studies. Phospholipids and EAs are dissolved in a basic solvent, such as methanol and chloroform together. After the solution is ready, it is poured into a flask with a circular bottom and rotated at a constant temperature (above the lipids' glass transition point) with less pressure [58]. Lipids and EA combine to produce a coating on the flask walls. Next, aqueous medium containing medication is used to hydrate the twisted film. Lipids inflate as a result, forming bilayer vesicles. The superior vesicles can be sonicated or extruded to create vesicles of the appropriate size [59].

Method of Reverse-Phase Evaporation

At this stage, the plan will change to a viscous gel, and then the vesicles will be arranged. Using centrifugation or dialysis, the non-encapsulated material and leftover solvents may become indifferentiable [60]. Lipids that have been dissolved in organic solvents are gathered using this approach in a flask with a circular bottom. EA-containing aqueous medium is introduced while nitrogen is being purge. Depending on the drug's solubility, it can be introduced to an aqueous or lipid media. After the mixture is produced, it is sonicated to convert it into a standardised dispersion. Following sonication, the system shouldn't separates until a minimum of half an hour. After that, the organic solvent is eliminated with little pressure [61, 62].

The Sonication Vortexing Method

To create a milky suspension, mixed lipids (such as phosphatidylcholine, EA, and the medicinal drug) are combined in phosphate buffer and vortexed using the vortexing sonication technique. After sonicating the suspension, it is extruded via polycarbonate membranes [63]. This technique, which entails combining cationic lipids – like DOTMA – with PBS to reach a concentration of 10 mg/ml and then counting sodium deoxycholate (SDC) – has also been used to establish cationic transfersomes. The mixture is then extruded through a polycarbonate (100 nm) filter after being vortexed and sonicated [64].

Method of Injecting Ethanol

This procedure involves heating the drug-containing aqueous solution to a steady temperature while continuously churning it. Phospholipids and EAs in an ethanolic solution are dropped one at a time towards a solution of water. Bilayered structures are formed by the precipitation of lipid molecules in the solution upon interaction with aqueous media. Compared to previous approaches, this procedure has several benefits, such as simplicity, repeatability, and scaling up [65].

Freeze-Thaw Technique

Using this technique, multilamellar vesicles are frozen by being exposed to alternating cycles of extremely low temperature and high temperature. After being moved to a tube, the geared-up suspension is submerged for 30 seconds in a nitrogen bath at −30°C. It is placed in a water bath at a high temperature following freezing. Nine instances, the same class is offered again [66].

MECHANISM OF PENETRATION

Under the right circumstances, transferosomes could move 0.1 mg of lipid per hour and square centimetre over undamaged skin. Compared to the value usually dictated by the transdermal

concentration gradients, this number is significantly greater. This elevated flux rate is caused by "transdermal osmotic gradients", which are naturally existing gradients that are available across the skin but are significantly more pronounced [67, 68]. The skin penetration barrier creates an osmotic gradient that keeps the viable section of the epidermis (75% water content) and nearly dry stratum corneum (15%) close and prevents the skin's surface from losing water. The osmotic gradient also keeps the skin from drying out [69].

A level that represents unphysiologically high transdermal loss of water, ambient air acts as a suitable sink for a water molecule, maintaining the gradient's stability. Every polar lipid draws a certain amount of water to it. This is because the hydrophilic lipid residues and associated proximal water interacted in an economically favourable way [70, 71]. Most lipid bilayers therefore naturally withstand induced dehydration. As a result, all polar lipid vesicles-derived lipid vesicles migrate from relatively dry locations to regions with a high enough concentration of water. Lipid vesicles detect this "osmotic gradient" and try to avoid total drying by travelling along it after applying lipid suspension (transferosome) to skin that has partially dried due to water evaporation loss (Figure 4) [72].

Much less deformation-resistant vesicles, such as standard liposomes, confine themselves to the skin's surface because they completely become dehydrated and fuse, giving them less penetration strength than the transferosomes. Only sufficiently deformable vesicles can pass through the skin's narrow pores because surfactant-based transferosomes possess more appropriate rheological and hydration characteristics compared to others, which accounts for their greater deformability (Table 2, 3) [73].

In this way, transferosomes are maximised in their flexibility, allowing them to fully utilize the transepidermal osmotic gradient (water concentration gradient). The stratum corneum's intracellular sealing lipids allow transferosomes to squeeze through and pass through the skin penetration barrier [74].

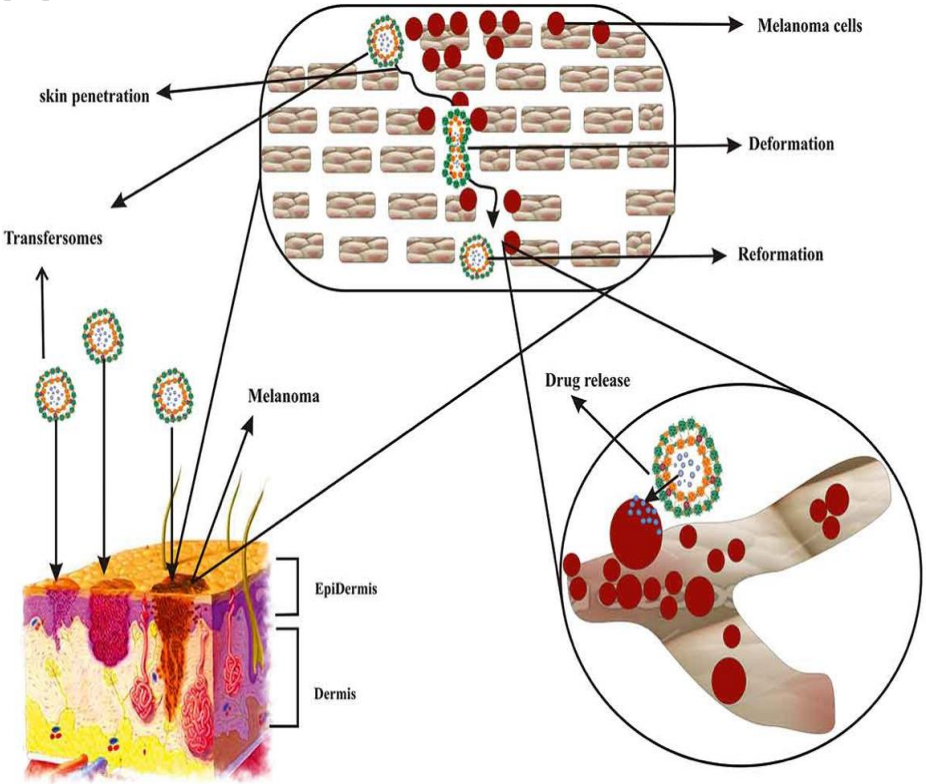

Figure 4. Mechanism of action of transferosomes [75].

Table 2. The use of transfersomes as medicinal agent carriers.

Therapeutic Agent	Therapeutic Category	Marketed Formulation	Investigations	Conclusions	Ref.
Ovalbumin and saponin	Anti-OVA antibody titer in serum		Created efficient vesicular formulations, such as ovalbumin and saponin ethosomes, liposomes, and transfersomes. The impact of formulation content on encapsulation of protein was examined, and the optimal formulation for each kind of vesicular formulation was chosen for in vivo transdermal immunisation in mice and their stability experiment.	The outcomes unequivocally showed that, when compared to the negative control, every formulation of nanolipid vesicles improve absorption of peptide into the skin, with the ethosome formulation producing the greatest serum antibody titers. Specifically, size ageing research showed that throughout a 2-month storage period, only ethosome remained consistent in terms of its combined size and polydispersity.	[76]
Diclofenac sodium	NSAID	Voltaren® gel	After being administered subcutaneously using a liquid jet injector, traditional liposomes and transfersomes loaded with diclofenac sodium were assessed for their controlled release properties and structural stability.	The new strategy combined the benefits of painless liquid injection devices with localised treatment, improving both effectiveness and security.	[77]
Osthole	Anti-fibrotic, anti-inflammatory		This study aimed to investigate the physical characteristics, skin in vitro penetration, and plasma in vivo concentrations of the osthole-loaded liposome, transfersome and ethosome	An in-vitro research shown that osthole ethosome reduced the lag time of 2.45 h and increased transdermal flow of 6.98 ± 1.6 μg/cm^2/h throughout the skin of pig ears. Based on information from in vivo pharmacokinetic tests, the osthole-loaded ethosome's AUC and Cmax significantly increased when compared to the remaining formulations.	[78]
Itraconazole	Antifungal	Sporanox®	Three distinct types of surfactants have been created in varying concentrations to load itaconazole into nanotransfersomes, which were then characterised. Mannitol was used to co-spray dry the optimised transferosomal formulations, and the dry powders' aerosolization effectiveness and aerodynamic properties were evaluated.	Lecithin-infused optimised nanotransfersomes: Span®60 has a small size distribution structure with a ratio of 90:10. The particle size was not considerably affected by the different kinds of surfactants. An analysis of the aerosolization of formulations that were co-sprayed dried with varying mannitol concentrations revealed that the most aerosolization efficient ratio was 2:1 for mannitol: transfersome (w:w).	[79]
Timolol maleate	Non-selective β-adrenergic receptor antagonist	Timoptol-XE gel	The current study's aim was to investigate the extrusion-based deformability features of transfersomes loaded with unlike timolol maleate (TM).	The outcomes demonstrated that TM-loaded transfersomes might enhance conventional TM delivery's bioavailability and corneal transmittance.	[80]
Piroxicam	NSAID	PX-TRS gel	Examined the primary composite design's optimisation and in vivo	Maximum elasticity and enhanced stability in its gel composition.	[81]

			investigation of piroxicam-loaded transethosomal gel.		
Asenapine maleate	Antipsychotic drug	*Saphris*®	Thin film hydration was used to create asenapine maleate transfersomes. Asenapine maleate skin penetration was tested using a range of chemical enhancers. Rats were used in an in vivo pharmacokinetic investigation to evaluate the bioavailability of transdermal vs oral treatment.	The augmentation of skin permeability was larger with 20% v/v ethanol. After 24 hours (Q24), the total quantity of asenapine maleate was absorbed due to the separate actions of transfersome and ethanol. Transdermal administration significantly increased bioavailability compared to the oral route, according to an in-vivo pharmacokinetic research.	[82]
Ketoprofen	NSAID	Fastum gel	To evaluate the efficacy of oral and Transfersome® gel ketoprofen in comparison to ketoprofen and drug-free SequessomeTM vesicles in lowering discomfort caused by soreness in the calves of healthy individuals following exercise that involved walking downstairs, they carried out an assigned, double-blind, controlled Phase II study.	The outcomes demonstrated that when it came to lowering muscular pain after exercise, Transfersome® gel, drug-free SequessomeTM vesicles and ketoprofen outperformed oral ketoprofen. Moreover, oral ketoprofen slowed down the healing process from muscular pain, while Transfersome® gel, drug-free SequessomeTM vesicles, and ketoprofen were not. Ketoprofen or without drugs SequessomeTM vesicles are recognised to be as successful in relieving joint pain associated with osteoarthritis as oral NSAIDs.	[83]
Emodin	Purgative, laxative	Regalia®	The film-ultrasonic dispersion approach was used to create the nano emodin transfersome (NET). For this study, sixty male rats were chosen. Serum lipid levels and fasting blood glucose were measured following an 8-week course of therapy. By using microscopy with light, the adipocyte amount and cellular diameter as well as the adipose tissue slice were assessed. The peri-renal fat tissue's mRNA expression of G0S2 and ATGL was measured using reverse transcription polymerase chain reaction.	The effects of NET on the body's weight, pathological fatty liver change, peripheral fat content, TG level, serum HDL-C level and adipocyte mass have all been linked to upregulated ATGL protein expression and downregulated G0S2 protein expression in the adipose tissue of obese rats. Together, these antagonistic interactions cause the body mass of obese rats to decrease.	[84]
Capsaicin	Antiarthritic agent	Zostrix cream	In this investigation, rat models were used to assess the antiarthritic effects of capsaicin-filled transfersome lipid vesicles. The test formulation's outcomes were contrasted with those of the industry-standard standard formulation, Thermagel (marketed gel).	The newly developed formulation was found to exhibit more effectively inhibitory activity (in reducing inflammations related to arthritis) than the marketed Thermagel formulation. This difference in penetrability between Thermagel and the uniquely developed transfersomal system of administration may be the reason for this observation.	[85]
Diclofenac	NSAID	Cambia	The purpose of this work was	In contrast to traditional	[86]

sodium			to increase the transdermal penetration of the weakly water-soluble medication diclofenac sodium by using transfersomes, ethosomes, and standard liposomes. The vesicular structures that were created were integrated into a 1% Carbopol 914 gel.	liposomes, hydroethanolic solution, or conventional gel, the ethosomes and transferosomes gave a noticeably larger quantity of accumulated penetration, constant-state flux, penetration coefficient, and residual medication into skin. According to stability testing, the vesicular formulations had been constant for a duration of three months. The findings showed that the skin was serving as a drug reservoir for the two different ethosome and transfersome formulations, prolonging the medicinal properties of diclofenac sodium.	
Terbinafine	Antifungals	Lamisil Dermgel	Researchers employed a range of microscopic methods, such as white-light microscopy, transmission electron microscopy (TEM), and scanning electron microscopy (SEM) to study the mechanisms behind the in vitro activity of terbinafine in Transfersome, it is necessary to evaluate the effects of TDT 067 and standard terbinafine on the morphology of T. rubrum, the main cause of onychomycosis.	Exposure to TDT 067 led to T. rubrum hyphae to undergo quick and significant ultrastructural alterations. In comparison with standard terbinafine, the drug caused total disruption of hyphae after a 24-hour period. After 30 minutes of being exposed to TDT 067, lipid droplets were seen underneath a TEM. After 24 hours, the intracellular gap had been filled. Subungual debris from patients treated with topical TDT 067 for onychomycosis validated these consequences in vivo.	[87]
Cinnamic acid	Anti-inflammatory, antioxidant		In this work, Sprague-Dawley rats were employed for dermal microdialysis sampling, and transfersomes filled with cinnamic acid were synthesised. When transfersomes are used as transdermal carriers, the quantity of medication released through the skin is comparable to that released by traditional liposomes.	The dermal medication concentrations using transfersomes put on skin were found to be significantly smaller than those needed with standard liposomes using an in vivo microdialysis sampling technique. Following a 10-hour period during which drug-containing transfersomes and liposomes that were applied to the abdomen skin areas of rats, the comparative liposomes' Cmax of cinnamic acid was 3.21 ± 0.25 mg/ml, while the transfersomes' Cmax was only 0.59 ± 0.02 mg/ml.	[88]
Terbinafine	Antifungal	Terbinex	Lipid vesicles that are ultradeformable to aid in the dissolution of terbinafine into the tissue around them and nail. The sole treatment for onychomycosis that is currently being developed is TDT 067 (terbinafine in transfersome), and we examined published clinical and preclinical research on this formulation.	This resulted in outstanding mycological cure rates and proof of a therapeutic impact in a trial where patients with onychomycosis received TDT 067 twice a day for a duration of 12 weeks. Over 700 patients received therapy for 48 weeks as part of an ongoing Phase III study to determine the efficacy and safety of TDT 067.	[89]

Ketoconazole	Antifungal	Nizoral Topical	Examined the possibility of employing transfersomes to distribute ketoconazole (KTZ) transdermally. KTZ was created using the lipid film hydration method with a rotary vacuum evaporator and appropriate essential oils that functioned as organic permeation enhancers. After being transformed into an appropriate gel formulation, the transfersomes are assessed for their gel properties, including drug content, homogeneity, pH, viscosity, spreadability, and extrudability.	Research demonstrated that the inclusion of appropriate permeation-enhancing agents to the formulation of transferosomes enhanced KTZ permeability and release, demonstrating that the permeation enhancers alter the skin's natural penetration barrier without changing the skin itself.	[90]
Curcuma longa extract	Photoprotective		Created creams with new vesicular systems (liposomes, transfersomes, and ethosomes) loaded with Curcuma longa extract, and evaluated their photoprotective efficacy using a Cutometer and a Sebumeter to measure skin moisture and sebum level	The outcomes show that extract-loaded transfersomes outperform ethosomes and liposomes in terms of enhancing skin characteristics. Vesicles filled with photoprotective herbal extract that are included in the creams may be very helpful as photoprotectives with increased skin moisture and sebum production.	[91]
Meloxicam	NSAID	Meloxicam 3% gel	Created and assessed transfersome and liposome vesicles for meloxicam (MX) transdermal drug delivery. Additionally, the effects of three different surfactants – sodium oleate (NaO, C18), dicetylphosphate (DCP, C32) and sodium cholate (NaChol, C24) – that were utilized for the preparation of transfersomes were examined.	The transfersomes exhibited a high efficiency of entrapment when surfactants with medium-sized carbon chains, such as NaO (C18) and NaChol (C24), were included. Compared to liposomes and MX solutions, transfersomes offer higher MX skin penetration.	[92]
Ketoprofen	NSAID	Orudis KT	Long-term research demonstrating the safety and effectiveness of topical NSAID usage over time has been published. Diractin (formerly known as IDEA-033) is an aqueous, viscous formulation that utilises transfersomes, an ultradeformable, self-regulating carrier, for the topical administration of ketoprofen.	For a maximum of 18 months (72 weeks), diractin offered sufficient pain alleviation with an excellent safety and tolerability characteristics.	[93]
Ketoprofen	NSAID	Vopac	The biodistribution and in vivo transportation of oral medication (Oruvail) and topical gel (Gabrilen) containing ketoprofen administered topically were compared in the paper.	The more favorable biodistribution and removal of ketoprofen from Diractin may have been due to skin's natural carrier-mediated drug transport, which guarantees localized and comparatively long-lasting drug evidence in the periphery.	
Tanshinone	Anti-hypertensive		After preparing the transfersomes utilizing the method of film dispersion and sonication, stability and deformation were examined.	The results of this research demonstrated the high entrapment stability and efficiency of transfersomes. When it comes to the external pressure and molar ratio of sodium cholate to lecithin, the vesicles are very deformable.	[94]

Regulatory Aspects of Transferosomes

A variety of novel excipients, including lipids, solvents, and surfactants have recently become accessible due to development within the pharmaceutical science field and expertise. However, there are currently concerns expressed by the community of scientists about the lifelessness of excipients and the possibility that they may have negative effects. The choice of excipient for a formulation based on transferosomes during research is constrained by issues related to toxicity and safety. Because of this, a limited selection of excipients may be used to plan a very porous drug delivery system. Consequently, inert excipients – which are utilised as solvents, vesicle-forming agents, surfactants, and EAs – are often tested when creating a formulation based on transfersomes. To reduce safety issues, a limited selection of excipients can be used to create a very permeable drug delivery system, which can be transfersome [95].

An anonymous list of pharmaceutical excipients categorized as "Generally Regarded as Safe" (GRAS), meaning they are those that have been clinically determined not to be toxic, has been maintained by several national regulatory bodies, including the World Health Organisation, the International Conference on Harmonization of Technical Requirements for Pharmaceuticals for Human Use, the US Food and Drug Administration (FDA), the International Pharmaceutical Excipients Council, and the Japanese Ministry of Health and Welfare. The FDA maintains a document called the "Inactive Ingredient Guide," which contains a list of approved excipients. The excipients having a value of their maximum dosage phase are described in this documentation using a meticulous method of administration or dosage form.

An essential component of a transfersome-oriented medication delivery system is phospholipid. Additionally, it is almost always accurate that vesicles with a fluid-chain somewhat elastic bilayer facilitate transportation of drug through skin barriers more effectively than liposomes, which are stiffer. As a result, almost all the phosphatidylcholine (PC) that is frequently employed to arrange stretchable liposomes is unsaturated PC, such as egg PC or soybean PC. SPC satisfies the requirements of the Food Chemicals Codex (http://www.NutriScienceUSA.com) and is a phospholipid that is GRAS-listed. Edge activators frequently belong to surfactant that simultaneously improves the elasticity of the lipid bilayer and destabilises it in elastic liposomes. Tween-80, Span-80, Tween-20, sodium cholate, and sodium deoxycholate were often utilised in the presence of EAs. Biju et al. suggested that oleic acid and other chemical penetration enhancers be employed in addition to EA in instead of the typically utilised surfactant. Mixed micelles' greater inflexibility and smaller size contribute to their survival, which also results in a reduced drug trap [96].

The behaviour of elastic liposomes as they penetrate the skin is significantly influenced by edge activator. To pick the best EA for optimal formulation, it is useful to have a general understanding of the distinctions between the various EAs. Sodium deoxycholate is an ionic surfactant that dissolves in water. Next, studies were conducted on valsartan-loaded elastic liposomes using sodium deoxycholate serving as the EA. According to this, although sodium cholate, an EA, is said to be not harmful, it has been classified as dangerous due to its ability to irritate skin, eyes, and respiratory systems. When used more than a particular concentration, surfactants can induce significant gastrointestinal distress; the maximum acceptable concentration range for surfactants is 10–25%. It is well known that ethanol effectively improves skin penetration. It has the capacity to interact between the group of polar head area of the lipid molecules, lowering the stratum corneum lipids melting point and boosting their fluidity and permeability through cell membranes [97].

FUTURE PROSPECTIVE

Actinic Keratosis

Actinic keratosis (AK) is a common skin condition brought on by prolonged exposure of sun. It often appears on the adult neck, face, shoulder blades, scalp baldness, backs of arms, and wrists; 75% of cases are said to be on the scalp, neck, and forearms. The appearance of keratotic macules, plaques or papules with surface scales on a red base is indicative of actinic keratosis. Lesions might hurt or itch, although they are usually asymptomatic. Because AK is a swollen syndrome, its frequency rises with age which means it is a common ailment in adults over the age of fifty. According to English

research, the prevalence rates for men and women were 15.4% and 5.9%, correspondingly. For both men and women over 70, this rate increased to 34.1 and 18.2%, respectively. A research study designed to investigate the incidence of AK found that those with Fitzpatrick skin type I – characterized by red hair and freckles – had higher AK rates. Similar, but with a stronger emphasis, increases were noted in Australia, where rates of prevalence of AK rose from 22 and 8% for men and women in the 30- to 39-year-old age range to 83 and 64%, correspondingly, in the 60- to 69-year-old age group [100].

Table 3. Examples of transfersomes drug delivery system patent publications [98, 99].

Patent Application No. (Year Of Issue/Publication/CPC Classification, etc.)	**Inventors**	**Comments**
US6165500 A (2000)	GregorCevc	The purpose of this creation is to describe the characteristics of unique configurations that are appropriate for the quick passage of various agents and other materials via constriction and permeability barriers. Transfersomes in the medium are applied to the skin inside the mammal with such a way that the animal absorbs an effective amount of the lipid, surfactant, or other medicinal substance connected to the transfersomes.
US20020048596 A1 (2002)	GregorCevc	The intellectual property rights assert that active ingredients like NSAIDs are included in transfersomes to facilitate passage across skin restriction and inherent obstacles. The transfersomes consist of two carrier components that differ by a factor of ten in their solubility in the suspension media.
US20060105955 A1 (2006)	Nicholas Perricone	The subject of the claim comprises compositions and techniques for transdermal medication administration, which include preparing a drug-containing phosphatidylcholine carrier composition and administering it topically. Claim including polypeptide molecules of medication encapsulated in crystallised phosphatidylcholine for transdermal administration of the polypeptide drug molecules
US7175850 B2 (2007)	GregorCevc	Revealed the use of transfersomes to provide corticosteroids (triamcinolone acetonide, hydrocortisone, and dexamethasone) to mice's skin to reduce oedema and protect against lucrative orientation treatment.
US20070042030 A1 (2007)	GregorCevc	Reported that >90% of the functional drug quantity was achieved in the intended body organ by the dermal administration of insulin using non-invasive transferosomes and comfortable management of diabetes mellitus type 2.
US7591949 B2 (2009)	Gregor, Cevc, Holger Richardsen, Andrea Weiland-Waibel	A kit as well as instrument for regulating the flow of penetrants through an adaptable absorbent barrier that is semi-permeable were claimed, along with a method that included the following steps: creating a mixture where the penetrants are suspended or dispersed in a polar liquid so that they take the shape of fluid droplets encircled through layering that resembles a membrane and has one or more layers.
WO2010/090654A1	Henry William, Kroon Henk-Andre, Summerton Linda	It is alleged that lipid, antimicrobial agent, and alternative surfactant compositions and their applications can be used to lessen the growth and viability of microorganisms. The alleged antifungal substance enters the membranes of phospholipid of the Polarisome or Spitzenkorper portions of the purported mycotic agent's hyphae.
US7867480 B1 (2011)	GregorCevc, Amla Chopra	The techniques for immunising animals to produce a resistive reaction, whether defensive or therapeutic are the subject of this invention. Makes claims about a new vaccination for non-invasive transdermal antigen injection using transfersomes that also include a chemical irritant and a complex that induces

		cytokines.
CA2919971 A1 (2015)	Richard Wolf Garraway, William Henry	The subject of the claim is vesicular compositions as well as ways of delivering agents of interest (AOIs) that are therapeutic, metabolic, cosmetic, or architectural. A surfactant, a lipid and an AOI are included in the claimed vesicular formulation. The AOI is attached to a vesicle component to ensure that an element from every molecule is beyond the vesicle and overall vesicular covering.
US20150157728 A1 (2015)	ModiPankaj	Advancement in a new stabilised and soluble formulation for cosmetic enhancements and the application of this topical formulation in relation to enhancing people's appearance. Declare that you have a low-viscosity, stabilised protein composition that may be applied topically and used to rescue an active ingredient by transdermal rescues for human cosmetic or medicinal purposes.

Regretfully, after topical treatment, 5-FU's anticancer efficacy was diminished due to its limited percutaneous penetration. The in vivo findings demonstrated that 5-FU vesiculization increases both the drug's cytotoxic impact and topical distribution. while compared to previous commercial formulations, a transdermal release of 5-FU-containing transfersomal gel shown up to a two-fold improvement in efficacy while treating AK and non-melanoma skin cancer.

Basal Cell Carcinoma

There is a noticeable environmental variation in the prevalence of carcinoma of basal cell. In South Wales, the age-standardized incidence of carcinoma of basal cells was 114 per 100,000 people in 1998, which was predicted. In Minnesota, USA, the yearly sex-standardized incidence and average age were reported to be 146 per 100,000. Australia has a higher rate (726 per 100,000). Basal cell carcinoma is often not well-reported to cancer registries; therefore, these numbers are probably under-values. The incidence has decreased by over ten percent annually in white populations in North America, mostly due to a 30% lifetime chance of developing carcinoma of basal cell. The illness is expected to become more of an issue in the future due to the ageing population [101].

According to Fadel et al., to potentially be used as a topical PDT photosensitizer for carcinoma of basal cell, the green indocyanine was enclosed in transfersomes, a type of colloidal vesicular nanocarrier.

Kaposi's Sarcoma

In 1872, Moritz Kaposi, a dermatologist from Hungary, published the first description of Kaposi's sarcoma (KS). Prior to the advancement of the human immunodeficiency virus (HIV) and the acquired immune deficiency syndrome (AIDS), KS was still relatively uncommon tumour. Although elderly men with Jewish ancestry from Italy or Eastern Europe have accounted for the most instances in North America and Europe, the neoplasm also affects another separate population, including young men in their adulthood of African descent, prepubescent children, recipients of renal allografts, and other patients undergoing immunosuppressive therapy. To differentiate it from the African, traditional, and transplant-related forms of the neoplasm, the widespread, fulminate type of KS linked to HIV illness is called epidemic KS.

Pathak et al. created paclitaxel deformable nanovesicles that may be employed for dermal chemotherapy, particularly in locations deep inside the dermis of KS associated with AIDS. Higher IC50 ($\leq$17) for transfersome was found in in vitro cytotoxicity research conducted on KSY-1 cell lines, compared to IC50 < 19 for transfersome gel. Confocal laser scanning microscopy verified that transfersomes may penetrate the skin's dermal layers through transfersome gel, which is the suggested target location [102].

Melanoma

The pigment melanin, which shields the body from UV light, is produced by dendritic cells called melanocytes, give birth to melanomas, which are horrible tumours. Tyrosine is used by melanocytes

to create melanin. Melanoma arises from the cancerous growth of an accumulation of melanocytes that create nevi, which are pigmented lesions or moles. Although melanocytes can originate from many parts of the body, more than 90% of melanomas have cutaneous cases and epidemiology, with the majority being discovered in the epidermis. Melanoma incidence differs geographically, peaking in North America, Australia, New Zealand, and Northern Europe. Melanoma is increasing among the quickest rates ever in the United States. The United States incidence rate grew from 7.9 to 17.7 per 100,000 people between 1975 and 2000 [103].

Lin et al. produced DPPC liposomes filled with 5-aminolevulinic acid (5-ALA) to cure melanoma. The findings showed that, in comparison to 5-ALA alone, the 5-ALA/DPPC formulation increased intracellular ROS accumulation, decreased cell viability, and mitochondria membrane electrical activity in melanoma cells. Additionally, by measuring the amount of 5-ALA that was transformed into protoporphyrin IX (PpIX) in the mice's skin used in the experiments, the 5-ALA/DPPC formulation demonstrated a higher capacity to penetrate the skin as compared to the 5-ALA in our ex vivo results. 5-ALA/DPPC increased PpIX build-up only in tumour tissue, not in regular skin, in melanoma xenograft models. siRNAs may be utilized therapeutically to address a range of dermatological conditions, including cancer, atopic dermatitis, and psoriasis [104].

Dorrani et al. first constructed a range of compositions of liposome with varied amounts of EA within their compositions, which allowed them to build a little connection of liposome–siRNA complexes (lipoplexes) with variable physicochemical characteristics. These liposomes were subsequently combined with siRNA with various ratios. Effective lipoplex permeability throughout the epidermal layers and accumulation in the top dermis were demonstrated by quantitative imaging analysis. Fluorescence, in addition to microscopy, the WST-1 cell proliferation assay, and in-cell immunofluorescence assay were utilized to examine the lipoplexes' capacity to internalise into cells of melanoma, inhibit the melanoma cells' ability to express the B-raf murine sarcoma viral oncogene homolog B1 (BRAF) protein and cause death of cells [105].

Squamous Cell Carcinoma (SCC)

Carcinoma of squamous cell is a kind of epithelial cancer that affects a variety of anatomic locations, including the lips, skin, mouth, oesophagus, urinary system, prostate, lungs, vagina, and cervix. These sites are often covered with squamous epithelium. The most common cancer that has the potential to spread metastatically both in the US and internationally is SCC. For all four subtypes, HPV and tobacco use are carcinogenic causes. All, a sizable number of warning signs are known for the main forms of SCC. It has been demonstrated that prolonged and intense sun exposure significantly raises a person's chance of getting skin cancer. Compared to persons with darker complexions, individuals with light complexions who burn but never get tan are considerably more prone to develop on-the-rise skin SCC [106] pro-transfersomes for the local cisplatin administration in cutaneous epithelial cancer. Improved pro-transfersomes ability to penetrate skin was demonstrated by the existence of a skin's fluorescent marker. System-wide in vivo performance findings indicated that the drug's therapeutic effectiveness had increased while its systemic toxicity had decreased [107–116].

CONCLUSION

The transdermal method has a long history of usage, and due to its inherent benefits, new techniques for transdermal administration are always being developed. Transferosomes, an ultra-deformable vesicle, will undoubtedly play a significant role in resuming research on the application of vesicles as transdermal drug delivery systems. When considering transdermal administration methods, using elastic vesicles offers the following benefits: their composition is safe and authorized for both pharmaceutical and cosmetic use; they are capable of supporting drug molecules with a broad range of solubility; they may improve transdermal flux, extending release and enhancing the location particularity of bioactive molecules; and they enable enhanced drug penetration through skin.

Therefore, using an ultra-deformable vesicular carrier to boost the distribution of bioactive chemicals through the skin presents both new obstacles and opportunity for the creation of innovative

and better therapeutics. As a result, it is possible to draw the conclusion that the novel, incredibly flexible drug carrier – the transferosome – can solve every issue related to transdermal delivery because these vesicles are specifically designed for responding to external stress by rapidly and cheaply changing their shape.

Acknowledgment

The Department of Pharmaceutics at ITS College of Pharmacy is acknowledged by the authors for its wonderful opportunity, helpful advice, and provision of the facilities required for the research.

Conflicts of Interest

The writers attest that there is not a conflict between their interests in the article's content.

REFERENCES

1. Richard C, Cassel S, Blanzat M.. Vesicular systems for dermal and transdermal drug delivery. RSC Adv. 2021;11:442–451. doi: 10.1039/D0RA09561C.
2. Moronkeji K, Todd S, Dawidowska I, Barrett SD, Akhtar R.. The role of subcutaneous tissue stiffness on microneedle performance in a representative in vitro model of skin. J. Control. Release. 2017;265:102–112. doi: 10.1016/j.jconrel.2016.11.004.
3. Karande P, Mitragotri S. Enhancement of transdermal drug delivery via synergistic action of chemicals. Biochim. et Biophys. Acta (BBA) Biomembr. 2009;1788:2362–2373. doi: 10.1016/j.bbamem.2009.08.015.
4. Alkilani AZ, Alkalbani R, Jaber D, Hamed R, Hamad I, Abumansour H, Assab MA. Knowledge, attitude, practice and satisfaction of patients using analgesic patches in Jordan. Trop. J. Pharm. Res. 2019;18:1745–1753.
5. Berner B, John VA. Pharmacokinetic characterisation of transdermal delivery systems. Clin. Pharmacokinet. 1994;26:121–134. doi: 10.2165/00003088-199426020-00005.
6. Parhi R, Mandru A. Enhancement of skin permeability with thermal ablation techniques: Concept to commercial products. Drug Deliv. Transl. Res. 2021;11:817–841. doi: 10.1007/s13346-020-00823-3.
7. Kurz A, Farlow M, Lefèvre G. Pharmacokinetics of a novel transdermal rivastigmine patch for the treatment of Alzheimer's disease: A review. Int. J. Clin. Pract. 2009;63:799–805. doi: 10.1111/j.1742-1241.2009.02052.x.
8. Lane ME. Skin penetration enhancers. Int. J. Pharm. 2013;447:12–21. doi: 10.1016/j.ijpharm.2013.02.040.
9. Hamed R, Al Baraghthi T, Alkilani AZ, Abu-Huwaij R.. Correlation between rheological properties and in vitro drug release from penetration enhancer-loaded Carbopol® gels. J. Pharm. Innov. 2016;11:339–351. doi: 10.1007/s12247-016-9262-9.
10. Hao Y, Li W, Zhou X, Yang F, Qian Z.. Microneedles-based transdermal drug delivery systems: A review. J. Biomed. Nanotechnol. 2017;13:1581–1597. doi: 10.1166/jbn.2017.2474.
11. Imam SS, Agarwal S. A pragmatic approach to treat lung cancer through loading Theaflavin-3, 3'-Digallate and Epigallocatechin Gallate in Spanlastic. Asian J Pharm Clin Res. 2021 Nov 7; 14(11): 1–8.
12. Imam SS. The future of non-invasive ways to treat cancer. Int J Pharm Sci & Res 2021;12(8): 4684–96.
13. Imam SS, Imam ST, Mdwasifathar, Kumar R, Ammar MY. Interaction between Ace 2 And Sars-Cov2, and use of EGCG and Theaflavin to treat Covid-19 in initial phases. Int J Curr Pharma Res. 2022 Mar;14(2):5– 10.
14. Imam SS, Sharma R. Natural compounds promising way to treat Lung Cancer. Int J Pharm Res Appl. 2023;8(2): 552– 558.
15. Imam SS, Sharma S, Kumari D, Khan S, Pathak P, Katiyar D. An Expedient Approach to Treat Asthma through Non-Steroidal, Natural Transferosomes Aerosol System. Innov J Med Sci . 2022;10(6): 7–11.
16. Imam SS, Imam ST, Agarwal S, Kumar R, Ammar MY, Athar MW, Akthar A. Lung Cancer Therapy Using Naturally Occurring Products and Nanotechnology. Innovare J Med Sci. 2022;10(4): 1–5.

17. Imam ST, Imam SS. The Cream which relieves the pain of Menstrual cramps without interfering with the Hormones or Period Cycle. Res J Pharm Techno. 2023;16(3):1239–6.
18. Imam SS. Topical Formulation Constituted with Transferosomes for the Treatment of Non-Melanoma Skin Cancer. Asian J Pharm Clin Res. 2023 May 7;16(5):27–32.
19. Imam SS. Nanoparticles: the future of drug delivery. Int J Curr Pharm Sci. 2023;15(6):8–15.
20. Ramadon D, McCrudden MT, Courtenay AJ, Donnelly RF. Enhancement strategies for transdermal drug delivery systems: current trends and applications. Drug Deliv Transl Res. 2022;4:758–91. doi: 10.1007/s13346-021-00909-6.
21. Akhtar N, Singh V, Yusuf M, Khan RA. Non-invasive drug delivery technology: development and current status of transdermal drug delivery devices, techniques and biomedical applications. Biomed Eng/Biomed Tech. 2020;65:243–72. doi: 10.1515/bmt-2019-0019.
22. Subedi RK, Oh SY, Chun MK, Choi HK. Recent advances in transdermal drug delivery. Arch Pharm Res. 2010;33:339–51. doi: 10.1007/s12272-010-0301-7.
23. Lee JW, Park JH, Prausnitz MR. Dissolving microneedles for transdermal drug delivery. Biomaterials. 2008;29:2113–24. doi: 10.1016/j.biomaterials.2007.12.048.
24. Finnin BC, Morgan TM. Transdermal penetration enhancers: applications, limitations, and potential. J Pharm Sci. 1999;88:955–8. doi: 10.1021/js990154g.
25. Arora A, Prausnitz MR, Mitragotri S. Micro-scale devices for transdermal drug delivery. Int J Pharm. 2008;364:227–36. doi: 10.1016/j.ijpharm.2008.08.032.
26. Zorec B, Préat V, Miklavčič D, Pavšelj N. Active enhancement methods for intra- and transdermal drug delivery: a review. Slov Med J. 2013;82:5.
27. Kling J, DeFrancesco L. The paper trail to commercialization. Nat Biotechnol. 2007;25:1217. doi: 10.1038/nbt1107–1217a.
28. Karande P, Jain A, Mitragotri S. Discovery of transdermal penetration enhancers by high-throughput screening. Nat Biotechnol. 2004;22:192–197. doi: 10.1038/nbt928.
29. Bozdaganyan ME., Orekhov PS. Synergistic Effect of Chemical Penetration Enhancers on Lidocaine Permeability Revealed by Coarse-Grained Molecular Dynamics Simulations. Membranes. 2021;11:410. doi:.3390/membranes11060410.
30. Cho CW, Shin SC. Enhanced transdermal delivery of atenolol from the ethylene-vinyl acetate matrix. Int J Pharm. 2004;287:67–71. doi:10.1016/j.ijpharm.2004.08.013.
31. Dragicevic N, Maibach HI. Percutaneous Penetration Enhancers Physical Methods in Penetration Enhancement. Springer; Berlin/Heidelberg, Germany: 2017.
32. Kanikkannan N, Singh M. Skin permeation enhancement effect and skin irritation of saturated fatty alcohols. Int J Pharm. 2002;248:219–228. doi:10.1016/S0378-5173(02)00454-4.
33. Maibach HI, Feldmann RJ. The effect of DMSO on percutaneous penetration of hydrocortisone and testosterone in man. Ann N Y Acad Sci. 1967;141:423–427.doi:10.1111/j.1749-6632.1967.tb34906.x.
34. Hadgraft J, Lane ME. Transdermal delivery of testosterone. Eur J Pharm. Biopharm. 2015;92:42–48. doi:10.1016/j.ejpb.2015.02.015.
35. Jaiswal J, Poduri R, Panchagnula R. Transdermal delivery of naloxone: Ex vivo permeation studies. Int J Pharm. 1999;179:129–134. doi: 10.1016/S0378-5173(98)00383-4.
36. Liu C, Guan Y, Tian Q, Shi X, Fang L.. Transdermal enhancement strategy of ketoprofen and teriflunomide: The effect of enhanced drug-drug intermolecular interaction by permeation enhancer on drug release of compound transdermal patch. Int J Pharm. 2019;572:118800. doi: 10.1016/j.ijpharm.2019.118800.
37. Ameen D, Michniak-Kohn B. Transdermal delivery of dimethyl fumarate for Alzheimer's disease: Effect of penetration enhancers. Int J Pharm. 2017;529:465–473. doi: 10.1016/j.ijpharm.2017.07.031.
38. Singh BN, Singh RB, Singh J. Effects of ionization and penetration enhancers on the transdermal delivery of 5-fluorouracil through excised human stratum corneum. Int J Pharm. 2005;298:98–107. doi:10.1016/j.ijpharm.2005.04.004.
39. Lee PJ, Langer R, Shastri VP. Role of n-methyl pyrrolidone in the enhancement of aqueous phase transdermal transport. J Pharm Sci. 2005;94:912–917. doi: 10.1002/jps.20291.

40. Ogiso T, Hata T, Iwaki M, Tanino T. Transdermal absorption of bupranolol in rabbit skin in vitro and in vivo. Biol. Pharm. Bull. 2001;24:588–591. doi:10.1248/bpb.24.588.
41. Van Zyl L, Du Preez J, Gerber M, Du Plessis J, Viljoen J. Essential fatty acids as transdermal penetration enhancers. J Pharm Sci. 2016;105:188–193. doi:10.1016/j.xphs.2015.11.032.
42. Stott PW, Williams AC, Barry BW. Mechanistic study into the enhanced transdermal permeation of a model β-blocker, propranolol, by fatty acids: A melting point depression effect. Int J Pharm. 2001;219:161–176. doi:10.1016/S0378-5173(01)00645-7.
43. Klimentová J, Kosák P, Vávrová K, Holas T, Hrabálek A. Influence of terminal branching on the transdermal permeation-enhancing activity in fatty alcohols and acids. Bioorganic Med. Chem. 2006;14:7681–7687. doi:10.1016/j.bmc.2006.08.013.
44. Melero A, Garrigues T, Almudever P, Martı A, Lehr C, Schäfer U. Nortriptyline hydrochloride skin absorption: Development of a transdermal patch. Eur J Pharm Biopharm. 2008;69:588–596. doi:10.1016/j.ejpb.2007.11.012.
45. Haq A, Michniak-Kohn B. Effects of solvents and penetration enhancers on transdermal delivery of thymoquinone: Permeability and skin deposition study. Drug Deliv. 2018;25:1943–1949. doi: 10.1080/10717544.2018.1523256.
46. Stahl J, Kietzmann M. The effects of chemical and physical penetration enhancers on the percutaneous permeation of lidocaine through equine skin. BMC Vet Res. 2014;10:1–6. doi: 10.1186/1746-6148-10-138.
47. Ogiso T, Iwaki M, Paku T. Effect of various enhancers on transdermal penetration of indomethacin and urea, and relationship between penetration parameters and enhancement factors. J Pharm Sci. 1995;84:482–488. doi:10.1002/jps.2600840418.
48. Vijaya C, Bingi M, Vigneshwaran L. Transdermal delivery of venlafaxine hydrochloride: The effects of enhancers on permeation across pig ear skin. Indian J Pharm Sci. 2011;73:456.
49. Björklund S, Engblom J, Thuresson K, Sparr E. Glycerol and urea can be used to increase skin permeability in reduced hydration conditions. Eur. J. Pharm. Sci. 2013;50:638–645. doi: 10.1016/j.ejps.2013.04.022.
50. Narishetty STK, Panchagnula R. Transdermal delivery of zidovudine: Effect of terpenes and their mechanism of action. J Control Release.2004;95:367–379. doi: 10.1016/j.jconrel.2003.11.022.
51. Jain AK, Thomas NS, Panchagnula R. Transdermal drug delivery of imipramine hydrochloride.: I. Effect of terpenes. J Control Release. 2002;79:93–101. doi: 10.1016/S0168-3659(01)00524-7.
52. Nokhodchi A, Shokri J, Dashbolaghi A, Hassan-Zadeh D, Ghafourian T, Barzegar-Jalali M. The enhancement effect of surfactants on the penetration of lorazepam through rat skin. Int J Pharm. 2003;250:359–369. doi:10.1016/S0378-5173(02)00554-9.
53. Piret J, Désormeaux A, Cormier H, Lamontagne J, Gourde P, Juhász J, Bergeron MG. Sodium lauryl sulfate increases the efficacy of a topical formulation of foscarnet against herpes simplex virus type 1 cutaneous lesions in mice. Antimicrob Agents Chemother. 2000;44:2263–2270. doi:10.1128/AAC.44.9.2263-2270.2000.
54. Akhtar N, Rehman M, Khan H, Rasool F, Saeed T, Murtaz G. Penetration enhancing effect of polysorbate 20 and 80 on the in vitro percutaneous absorption of lascorbic acid. Trop J Pharm Res. 2011;10:3.doi:10.4314/tjpr.v10i3.1.
55. Abdulbaqi IM, Darwis Y, Khan NA, Assi RA, Khan AA. Ethosomal nanocarriers: The impact of constituents and formulation techniques on ethosomal properties, in vivo studies, and clinical trials. Int J Nanomed. 2016;11:2279–2304. doi:10.2147/IJN.S105016.
56. Bhardwaj P, Tripathi P, Gupta R, Pandey S. Niosomes: A review on niosomal research in the last decade. J Drug Deliv Sci Technol. 2020;56:101581. doi: 10.1016/j.jddst.2020.101581
57. Bozzuto G, Molinari A. Liposomes as nanomedical devices. Int J Nanomed. 2015;10:975–99. doi: 10.2147/IJN.S68861.
58. Chacko IA, Ghate VM, Dsouza L, Lewis SA. Lipid vesicles: a versatile drug delivery platform for dermal and transdermal applications. Colloids Surf B Biointerfaces. 2020;195:111262. doi: 10.1016/j.colsurfb.2020.111262
59. Babaie S, Bakhshayesh ARD, Ha JW, Hamishehkar H, Kim KH. Invasome: a novel nanocarrier for transdermal drug delivery. Nanomaterials. 2020;10:341. doi: 10.3390/nano10020341

60. Jain S, Jain V, Mahajan SC. Lipid based vesicular drug delivery systems. Adv Pharm. 2014;2014:574673. doi: 10.1155/2014/574673
61. Pandita A, Sharma P. Pharmacosomes: an emerging novel vesicular drug delivery system for poorly soluble synthetic and herbal drugs. ISRN Pharm. 2013;2013:348186. doi: 10.1155/2013/348186.
62. Witika BA, Mweetwa LL, Tshiamo KO, Edler K, Matafwali SK, Ntemi PV, Chikukwa MTR, Makoni PA. Vesicular drug delivery for the treatment of topical disorders: Current and future perspectives. J Pharm Pharmacol. 2021;73:1427–41. doi: 10.1093/jpp/rgab082.
63. Elsharkasy OM, Nordin JZ, Hagey DW, de Jong OG, Schiffelers RM, Andaloussi SEL, Vader P. Extracellular vesicles as drug delivery systems: why and how? Adv Drug Deliv Rev. 2020;159:332–43. doi: 10.1016/j.addr.2020.04.004.
64. Nakhaei P, Margiana R, Bokov DO, Abdelbasset WK, Jadidi Kouhbanani MA, Varma RS, Marofi F, Jarahian M, Beheshtkhoo N. Liposomes: structure, biomedical applications, and stability parameters with emphasis on cholesterol. Front Bioeng Biotechnol. 2021;9:748. doi: 10.3389/fbioe.2021.705886.
65. Nayak D, Tippavajhala VK. A comprehensive review on preparation, evaluation and applications of deformable liposomes. Iran J Pharm Res. 2021;20:186–205.
66. Alavi M, Karimi N, Safaei M. Application of various types of liposomes in drug delivery systems. Adv Pharm Bull. 2017;7:3–9. doi: 10.15171/apb.2017.002.
67. Hussain A, Singh S, Sharma D, Webster TJ, Shafaat K, Faruk A. Elastic liposomes as novel carriers: recent advances in drug delivery. Int J Nanomed. 2017;12:5087–108. doi: 10.2147/IJN.S138267.
68. Ntimenou V, Fahr A, Antimisiaris SG. Elastic vesicles for transdermal drug delivery of hydrophilic drugs: a comparison of important physicochemical characteristics of different vesicle types. J Biomed Nanotechnol. 2012;8:613–23. doi: 10.1166/jbn.2012.1426.
69. Romero EL, Morilla MJ. Ultradeformable phospholipid vesicles as a drug delivery system: a review. Res Rep Transdermal Drug Deliv. 2015;4:55–69. doi: 10.2147/RRTD.S50370.
70. Sudhakar K, Fuloria S, Subramaniyan V, Sathasivam KV, Azad AK, Swain SS, Sekar M, Karupiah S, Porwal O, Sahoo A, et al. Ultraflexible liposome nanocargo as a dermal and transdermal drug delivery system. Nanomaterials. 2021;11:2557. doi: 10.3390/nano11102557.
71. Rai S, Pandey V. Transfersomes as versatile and flexible nano-vesicular carriers in skin cancer therapy: the state of the art. Nano Rev. 2017;8:1325708. doi: 10.1080/20022727.2017.1325708.
72. Opatha SAT, Titapiwatanakun V, Chutoprapat R. Transfersomes: a promising nanoencapsulation technique for transdermal drug delivery. Pharmaceutics. 2020;12:855. doi: 10.3390/pharmaceutics12090855.
73. Akram MW, Jamshaid H, Rehman FU, Zaeem M, Khan JZ, Zeb A. Transfersomes: a revolutionary nanosystem for efficient transdermal drug delivery. AAPS Pharm Sci Tech. 2021;23:7. doi: 10.1208/s12249-021-02166-9.
74. Duangjit S, Opanasopit P, Rojanarata T, Ngawhirunpat T. Characterization and in vitro skin permeation of meloxicam-loaded liposomes versus transfersomes. J Drug Deliv. 2011;2011:418316. doi: 10.1155/2011/418316.
75. Sardana V, Burzynski J, Zalzal P. Safety and efficacy of topical ketoprofen in transfersome gel in knee osteoarthritis: a systematic review. Musculoskelet Care. 2017;15:114–21. doi: 10.1002/msc.1163.
76. Bnyan R, Khan I, Ehtezazi T, Saleem I, Gordon S, O'Neill F, Roberts M. Formulation and optimisation of novel transfersomes for sustained release of local anaesthetic. J Pharm Pharmacol. 2019;71:1508–19. doi: 10.1111/jphp.13149.
77. Cevc G. Transdermal drug delivery of insulin with ultradeformable carriers. Clin Pharmacokinet. 2003;42:461–74. doi: 10.2165/00003088-200342050-00004.
78. Cevc G, Blume G, Schätzlein A. Transfersomes-mediated transepidermal delivery improves the regio-specificity and biological activity of corticosteroids in vivo. J Control Release. 1997;45:211–26. doi: 10.1016/S0168-3659(96)01566-0.
79. Chen S, Hanning S, Falconer J, Locke M, Wen J. Recent advances in non-ionic surfactant vesicles (niosomes): fabrication, characterization, pharmaceutical and cosmetic applications. Eur J Pharm Biopharm. 2019;144:18–39. doi: 10.1016/j.ejpb.2019.08.015.

80. Khoee S, Yaghoobian M. Chapter 6—Niosomes: a novel approach in modern drug delivery systems. In: Andronescu E, Grumezescu AM, editors. Nanostructures for drug delivery. Elsevier; Amsterdam, The Netherlands: 2017. p. 207–37.
81. Masjedi M, Montahaei T. An illustrated review on nonionic surfactant vesicles (niosomes) as an approach in modern drug delivery: fabrication, characterization, pharmaceutical, and cosmetic applications. J Drug Deliv Sci Technol. 2021;61:102234. doi: 10.1016/j.jddst.2020.102234.
82. Durak S, Esmaeili Rad M, Alp Yetisgin A. Niosomal drug delivery systems for ocular disease—recent advances and future prospects. Nanomaterials. 2020;10:1191. doi: 10.3390/nano10061191.
83. Ge X, Wei M, He S, Yuan WE. Advances of non-ionic surfactant vesicles (niosomes) and their application in drug delivery. Pharmaceutics. 2019;11:55. doi: 10.3390/pharmaceutics11020055.
84. Khan R, Irchhaiya R. Niosomes: A potential tool for novel drug delivery. J Pharm Investig. 2016;46:195–204. doi: 10.1007/s40005-016-0249-9.
85. El-Ridy MS, Yehia SA, Mohsen AM, El-Awdan SA, Darwish AB. Formulation of niosomal gel for enhanced transdermal lornoxicam delivery: in vitro and in vivo evaluation. Curr Drug Deliv. 2018;15:122–33. doi: 10.2174/1567201814666170224141548.
86. Patel KK, Kumar P, Thakkar HP. Formulation of niosomal gel for enhanced transdermal lopinavir delivery and its comparative evaluation with ethosomal gel. AAPS Pharm Sci Tech. 2012;13:1502–10. doi: 10.1208/s12249-012-9871-7.
87. Honeywell-Nguyen PL, Bouwstra JA. The in vitro transport of pergolide from surfactant-based elastic vesicles through human skin: a suggested mechanism of action. J Control Release. 2003;86:145–56. doi: 10.1016/S0168-3659(02)00415-7.
88. El Maghraby GM, Barry BW, Williams AC. Liposomes and skin: from drug delivery to model membranes. Eur J Pharm Sci. 2008;34:203–22. doi: 10.1016/j.ejps.2008.05.002.
89. Benson HAE, Grice JE, Mohammed Y, Namjoshi S, Roberts MS. Topical and transdermal drug delivery: from simple potions to smart technologies. Curr Drug Deliv. 2019;16:444–60. doi: 10.2174/1567201816666190201143457.
90. Halnor V, Pande V, Borawake D, Nagare H. Nanoemulsion: A novel platform for drug delivery system. J Mat Sci Nanotech. 2018;6:104.
91. Hamed R, Basil M, AlBaraghthi T, Sunoqrot S, Tarawneh O. Nanoemulsion-based gel formulation of diclofenac diethylamine: Design, optimization, rheological behavior and in vitro diffusion studies. Pharm Dev Technol. 2016;21:980–9. doi: 10.3109/10837450.2015.1086372.
92. Abu-Huwaij R, Al-Assaf SF, Hamed R. Recent exploration of nanoemulsions for drugs and cosmeceuticals delivery. J Cosmet Dermatol. 2021. doi: 10.1111/jocd.14704.
93. McClements DJ. Nanoemulsions versus microemulsions: terminology, differences, and similarities. Soft Matter. 2012;8:1719–29. doi: 10.1039/C2SM06903B.
94. Hamed R, Al-Adhami Y, Abu-Huwaij R. Concentration of a microemulsion influences the mechanical properties of ibuprofen in situ microgels. Int J Pharm. 2019;570:118684. doi: 10.1016/j.ijpharm.2019.118684.
95. Hamed R, Farhan A, Abu-Huwaij R, Mahmoud NN, Kamal A. Lidocaine microemulsion-laden organogels as lipid-based systems for topical delivery. J Pharm Innov. 2019;15:1–14. doi: 10.1007/s12247-019-09399-z.
96. Ganesan P, Karthivashan G, Park SY, Kim J, Choi DK. Microfluidization trends in the development of nanodelivery systems and applications in chronic disease treatments. Int J Nanomed. 2018;13:6109. doi: 10.2147/IJN.S178077.
97. Qian C, McClements DJ. Formation of nanoemulsions stabilized by model food-grade emulsifiers using high-pressure homogenization: factors affecting particle size. Food Hydrocoll. 2011;25:1000–8. doi: 10.1016/j.foodhyd.2010.09.017.
98. Hashtjin AM, Abbasi S. Nano-emulsification of orange peel essential oil using sonication and native gums. Food Hydrocoll. 2015;44:40–8. doi: 10.1016/j.foodhyd.2014.08.017.
99. Liu W, Sun D, Li C, Liu Q, Xu J. Formation and stability of paraffin oil-in-water nano-emulsions prepared by the emulsion inversion point method. J Colloid Interface Sci. 2006;303:557–63. doi: 10.1016/j.jcis.2006.07.055.

100. Izquierdo P, Esquena J, Tadros TF, Dederen C, Garcia M, Azemar N, et al. Formation and stability of nano-emulsions prepared using the phase inversion temperature method. Langmuir. 2002;18:26–30. doi: 10.1021/la010808c.
101. Azmi NAN, Elgharbawy AA, Motlagh SR, Samsudin N, Salleh HM. Nanoemulsions: Factory for food, pharmaceutical and cosmetics. Processes. 2019;7:617. doi: 10.3390/pr7090617.
102. Devarajan V, Ravichandran V. Nanoemulsions: As modified drug delivery tool. Int J Compr Pharm. 2011;2:1–6.
103. Chavda VP, Shah D. A review on novel emulsification technique: a nanoemulsion. J Pharmacol Toxicol Stud. 2017;5:32–3.
104. Sutradhar KB, Amin ML. Nanoemulsions: increasing possibilities in drug delivery. Eur J Nanomed. 2013;5:97–110. doi: 10.1515/ejnm-2013-0001.
105. Hamed R, Mahmoud NN, Alnadi SH, Alkilani AZ, Hussein G. Diclofenac diethylamine nanosystems-loaded bigels for topical delivery: development, rheological characterization, and release studies. Drug Dev Ind Pharm. 2020;46:1705–15. doi: 10.1080/03639045.2020.1820038.
106. Koroleva M, Nagovitsina T, Yurtov E. Nanoemulsions stabilized by non-ionic surfactants: stability and degradation mechanisms. Phys Chem Chem Phys. 2018;20:10369–77. doi: 10.1039/C7CP07626F.
107. Fernandes AR, Sanchez-Lopez E, Santos Td, Garcia ML, Silva AM, Souto EB. Development and characterization of nanoemulsions for ophthalmic applications: Role of cationic surfactants. Materials. 2021;14:7541. doi: 10.3390/ma14247541.
108. Fraga M, de Carvalho TG, da Silva Diel D, Bruxel F, Teixeira HF, Matte UC. Cationic nanoemulsions as a gene delivery system: proof of concept in the mucopolysaccharidosis I murine model. J Nanosci Nanotechnol. 2015;15:810–6. doi: 10.1166/jnn.2015.9179.
109. Kundu P, Agrawal A, Mateen H, Mishra IM. Stability of oil-in-water macro-emulsion with anionic surfactant: effect of electrolytes and temperature. Chem Eng Sci. 2013;102:176–85. doi: 10.1016/j.ces.2013.07.050.
110. Ribeiro RCdA, Barreto SMA, Ostrosky EA, Rocha-Filho PAd, Veríssimo LM, Ferrari M. Production and characterization of cosmetic nanoemulsions containing Opuntia ficus-indica (L.) Mill extract as moisturizing agent. Molecules. 2015;20:2492–2509. doi: 10.3390/molecules20022492.
111. Hamed R, Seder BY, Bardaweel SK, Qawass H. Lipid-based formulations of microemulsion-loaded oleogels for the oral delivery of carvedilol. J Dispers Sci Technol. 2021:1–11. doi: 10.1080/01932691.2021.1964987.
112. Praveen Kumar G, Divya A. Nanoemulsion based targeting in cancer therapeutics. Med Chem. 2015;5:272–84. doi: 10.4172/2161-0444.1000275.
113. Lovelyn C, Attama AA. Current state of nanoemulsions in drug delivery. J Biomater Nanobiotechnol. 2011;2:626. doi: 10.4236/jbnb.2011.225075.
114. Shaker DS, Ishak RA, Ghoneim A, Elhuoni MA. Nanoemulsion: A review on mechanisms for the transdermal delivery of hydrophobic and hydrophilic drugs. Sci Pharm. 2019;87:17. doi: 10.3390/scipharm87030017.
115. Zaid Alkilani A, Hamed R, Hussein G, Alnadi S. Nanoemulsion-based patch for the dermal delivery of ascorbic acid. J Dispers Sci Technol. 2021:1–11. doi: 10.1080/01932691.2021.1880924.
116. Zhengguang L, Jie H, Yong Z, Jiaojiao C, Xingqi W, Xiaoqin C. Study on the transdermal penetration mechanism of ibuprofen nanoemulsions. Drug Dev Ind Pharm. 2019;45:465–73. doi: 10.1080/03639045.2018.1546317.

