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Invasomal Technology: Bridging the Gap Between Drug Penetration and Therapeutic Efficacy

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ABSTRACT

Invasomal technology represents an advanced approach in vesicular drug delivery aimed at improving topical and transdermal drug administration. Invasomes are soft, deformable lipid vesicles primarily composed of phospholipids, ethanol, and terpenes. These components synergistically alter the structure of the stratum corneum, thereby enhancing drug permeation into deeper skin layers and improving therapeutic outcomes. This review discusses the fundamental aspects of invasomal systems, including their composition, mechanism of skin penetration, preparation techniques, characterization methods, and therapeutic applications. Due to their elasticity and penetration-enhancing properties, invasomes demonstrate superior performance compared to conventional liposomes and other vesicular carriers. They can effectively encapsulate and deliver both hydrophilic and lipophilic drugs across the skin barrier. Recent research highlights their expanding applications in dermatology, systemic therapy, and cosmetic formulations, contributing to improved bioavailability, controlled drug release, and enhanced targeting efficiency. Despite these advantages, certain limitations persist, such as formulation instability, difficulties in large-scale manufacturing, regulatory challenges, and the need for comprehensive safety evaluation. Emerging investigations are exploring their potential roles in gene therapy, cancer treatment, and vaccine delivery. Overall, invasomes represent a promising and versatile platform capable of overcoming the limitations associated with traditional transdermal systems. However, although invasomes showed 2–7 fold higher permeation compared to liposomes, their performance was formulation-dependent, particularly influenced by terpene concentration and vesicle size.

Keywords: Invasomes; Transdermal Drug Delivery; Topical Drug Delivery; Vesicular Drug Carriers; Skin Penetration Enhancement

INTRODUCTION

The skin is the largest organ of the human body and is structurally divided into three primary layers: the epidermis, dermis, and subcutaneous tissue. Beyond its protective role, the skin also serves as an important route for drug administration, enabling delivery to specific skin layers as well as to the systemic circulation[1,2,3]. Transdermal drug delivery systems (TDDS) provide a non-invasive alternative to oral and injectable routes, thereby improving patient comfort and compliance. The outermost layer of the skin, the stratum corneum, functions as the principal barrier against environmental stressors and prevents excessive trans epidermal water loss. Its intercellular lipid matrix is crucial for maintaining structural stability and barrier integrity[4]. TDDS formulations are designed to deliver therapeutically effective drug concentrations across the skin over a defined period. The first FDA-approved transdermal patch, transdermal SCOP, was introduced in 1979 for the prevention of motion sickness. Most transdermal systems are engineered to release drugs in a controlled, near zero-order manner for extended durations, which is advantageous in managing chronic conditions. Despite these benefits, the stratum corneum presents a significant obstacle to drug permeation[7,12]. Various enhancement strategies have been developed to overcome this barrier, including physical approaches such as ultrasound, electroporation, and iontophoresis, as well as formulation-based techniques using chemical enhancers, specialized vehicles, and nanocarriers[9,10,11,15]. However, despite encouraging permeation outcomes, the clinical translation of advanced vesicular systems such as invasomes requires careful regulatory evaluation, large-scale manufacturing standardization, and comprehensive long-term safety assessment. Vesicular systems are particularly promising due to their adaptable size, flexibility, and surface characteristics[16,17]. Although conventional liposomes can encapsulate both hydrophilic and lipophilic drugs[18], their limited ability to penetrate deeper skin layers restricts their transdermal application[19]. In contrast, elastic vesicles containing penetration enhancers demonstrate improved skin interaction and enhanced drug delivery efficiency[20,21]. Therefore, this review aims to critically analyze invasomal technology with emphasis on composition, penetration mechanism, comparative performance, therapeutic applications, and future clinical translation challenges.

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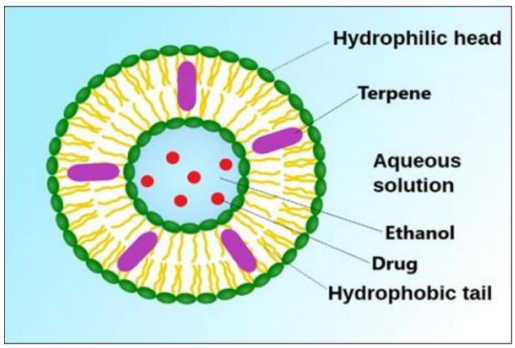

Figure 1. Structure of Invasome.

1.1 Overview of Invasomes

1.1.1 Definition and Concept of Invasomes

Invasomes are specialized lipid-based nanocarriers developed to enhance drug permeation through the skin by overcoming the protective function of the stratum corneum. They are modified vesicular systems comparable to liposomes but differ due to the inclusion of ethanol and terpene-based penetration enhancers such as menthol, cineole, and limonene[21]. These additional components improve their ability to cross the skin barrier more effectively than conventional vesicles[22]. The structure of invasomes is based on a flexible phospholipid bilayer, commonly composed of phosphatidylcholine, surrounding an aqueous core. This arrangement enables the encapsulation of both lipophilic and hydrophilic drugs[23]. Ethanol is incorporated into the lipid membrane to increase its fluidity and elasticity, allowing the vesicles to deform and pass through the narrow intercellular pathways of the skin. Terpenes further support drug penetration by interacting with the lipid matrix of the stratum corneum, temporarily altering its organization and reducing barrier resistance. They may also contribute to maintaining vesicle stability. Because of this combined structural and functional design, invasomes demonstrate enhanced permeability and flexibility. The lipid bilayer efficiently carries lipophilic compounds, while the aqueous core provides a suitable environment for hydrophilic drugs. By integrating phospholipids, ethanol, and terpenes into a single delivery system, invasomes form adaptable and efficient carriers, showing significant promise for transdermal drug delivery applications due to their hybrid composition and deformable nature[24]. Invasomes were first developed in 2002 by Professor Alfred Fahr and his research team[25]. These vesicular systems are based on liposomal structures but are modified by incorporating small quantities of ethanol along with terpenes or terpene blends. This unique composition enhances their ability to penetrate deeper layers of the skin, making them effective carriers for drug delivery. Compared to conventional liposomes and even ethosomes, invasomes demonstrate superior skin permeation capacity. They provide several benefits, including enhanced therapeutic effectiveness, improved patient compliance, and greater comfort during treatment[26],[27].

Table 1: Difference between different somes

Characteristics	Invasomes	Liposomes	Niosomes	Phytosomes	Transfersomes	Flexosomes
Composition	Phospholipids with ethanol and terpenes (penetration enhancers)	Phospholipid bilayer ± cholesterol	Non-ionic surfactants + cholesterol	Phospholipids complexed with plant actives	Phospholipids with edge activators	Phospholipids with flexible membrane enhancers
Active Ingredient Delivery	Targets deeper skin layers	Suitable for hydrophilic & lipophilic drugs	Mainly hydrophilic drugs	Plant-derived bioactives	Delivers drugs through elastic deformation	Enhanced delivery via flexible membrane
Key Feature	Enhanced permeation due to ethanol + terpenes	Bi-layer vesicle system	Surfactant-based vesicle	Improved bioavailability of herbal actives	Highly deformable elastic vesicle	High membrane flexibility
Penetration Mechanism	Lipid disruption + vesicle deformability	Limited penetration through SC	Surfactant-induced disruption	Lipid interaction with plant complex	Elastic deformation across SC	Flexible vesicle penetration

Permeation Efficiency	2–7 fold increase reported in studies	Moderate	Moderate	Moderate	High	High
Stability	Moderate; risk of oxidation	High	Good but leakage possible	High	Moderate	Good with controlled release
Applications	Transdermal drug delivery, dermatology	Cosmetics, vaccines, pharmaceuticals	Cosmetics, pharmaceuticals	Nutraceuticals, phytotherapy	Pain management, hormone therapy	Anti-aging, cosmetic delivery
Market Status	Research stage; no FDA-approved product	Widely commercialized	Commercially available	Growing nutraceutical market	Used in some clinical products	Emerging cosmetic technology

1.1.2 Invasomes In Comparison with Liposomes

Liposomes are vesicular carriers primarily composed of phospholipids that may be anionic, cationic, or neutral, often combined with cholesterol to enhance membrane stability. These systems are capable of encapsulating drugs with different physicochemical properties. Lipophilic drugs are typically embedded within the lipid bilayer, hydrophilic drugs are entrapped in the internal aqueous core, and amphiphilic drugs are distributed at the interface between the lipid layers[28],[29]. In comparison, invasomes are modified, highly deformable liposomal vesicles composed of phospholipids, ethanol, and one or more terpenes. The incorporation of ethanol increases membrane fluidity, producing a more flexible and less rigid vesicular structure than conventional liposomes, which enhances their ability to permeate through the skin[30]. Terpenes further promote drug penetration by interacting with and disturbing the densely packed lipid arrangement of the stratum corneum[31] (Figure 2).Microscopic characterization highlights structural differences among vesicular systems (Figure 3). Scanning electron microscopy (SEM) images indicate that liposomes, invasomes, and transfersomes generally exhibit smooth surfaces with a spherical shape (Figure 3A–C). Transmission electron microscopy (TEM) analysis shows that liposomes and invasomes are predominantly unilamellar in structure (Figure 3D, E), whereas transfersomes may display both unilamellar and multilamellar configurations (Figure 3F).

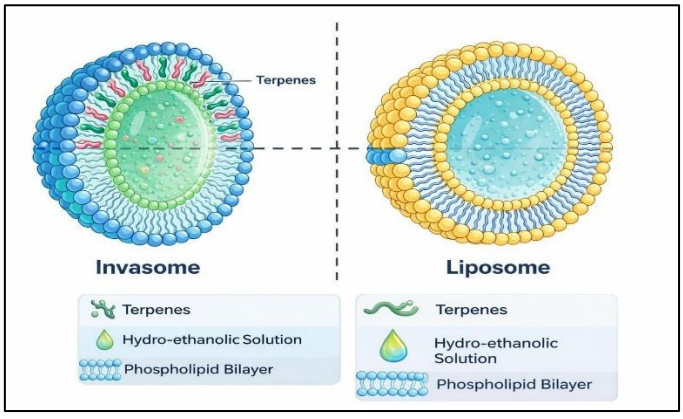

Figure 2. Invasome versus liposome.

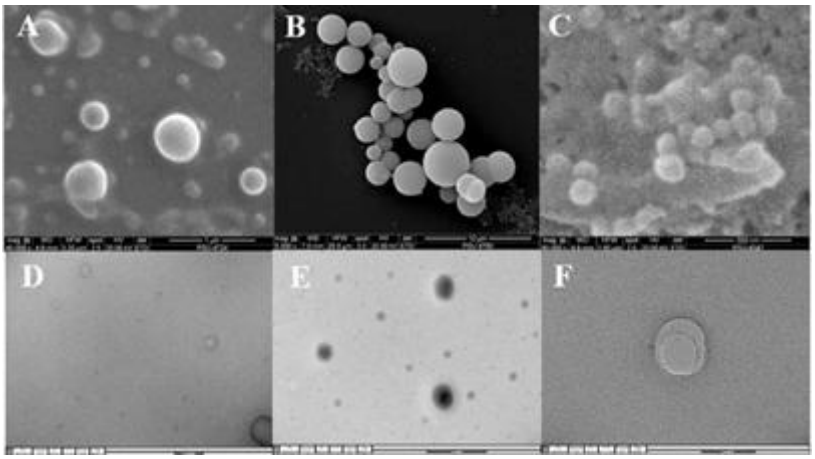

Figure 3. SEM photographs of liposome (A), invasome (B), and transfersome formulations (C), and TEM photographs of liposome (D), invasome (E), and transfersome formulations (F). Reprinted with permission from reference [32].

1.1.3 Advantages of Invasomes

• Non-invasive method of drug delivery

• Improved drug administration through the skin for transdermal therapy

• Ability to deliver both lipophilic and hydrophilic drugs

• Contains non-toxic ingredients in the formulation

• Improved patient compliance since the drug can be administered in semisolid dosage forms (gel or cream)

• Compared to phonophoresis, iontophoresis, and other complex procedures, this is a simple method of drug delivery[32,34]

1.1.4 Disadvantages of Invasomes

• High production cost

• Leakage and fusion of drugs or molecules from the vesicles

• Stability of invasomes may be affected by hydrolysis or oxidation of phospholipids[34]

1.2 Effect of Composition on the Physicochemical Characteristics of Invasomes

1.2.1 Effect of Ethanol

The inclusion of ethanol in lipid nanovesicles is a well-established strategy for increasing membrane fluidity[36,37]. Ethanol interacts with lipid components within the polar regions of the stratum corneum (SC), leading to alterations in both keratin-rich and lipid domains. This interaction lowers the lipid phase transition temperature, resulting in increased lipid mobility and partial disruption of the tightly packed SC structure[37,26]. Ethanol-containing nanocarriers enhance the flexibility of the intercellular lipid matrix by promoting greater rotational movement of lipid acyl chains. As a result, the vesicular membrane becomes more fluid and deformable, creating a softer structure compared to conventional liposomes[31]. This increased deformability facilitates improved skin permeation.Beyond its role in penetration enhancement, ethanol also contributes to the physical stability of invasomes. It can induce a net negative surface charge on vesicles, generating electrostatic repulsion between particles. This effect reduces vesicle aggregation and helps maintain formulation stability during storage[36,23,38,39].

1.2.2 Effect of Terpenes

1.2.2.1 Effect of Terpenes on Penetration

X-ray diffraction and differential scanning calorimetry (DSC) analyses have demonstrated that terpenes facilitate drug permeation by disturbing the ordered lipid arrangement of the stratum corneum (SC). These compounds interfere with the rigid lipid bilayers and reduce lipid packing density, leading to enhanced membrane fluidity. Terpenes promote drug transport by increasing diffusion through intercellular lipid pathways, disrupting hydrogen bonding within SC lipids, and extracting certain lipid components, thereby loosening the barrier structure.Research by Dragicevic-Curic *et al*. showed that combining different terpenes can produce a synergistic enhancement effect on temoporfin delivery. Invasomes formulated with a 1% blend of citral, cineole, and limonene demonstrated greater permeability compared to vesicles containing 1% citral alone. Additionally, drug penetration was found to be dependent on terpene concentration. Vesicles incorporating 1% terpenes achieved approximately 1.7 times higher skin permeation than those containing 0.5% terpenes. These findings suggest that loading temoporfin into vesicles with 1% terpene content may significantly improve its depth of skin penetration[40].

1.2.2.2 Effect of Terpenes on the Size of Invasomes

Particle size evaluation has demonstrated that invasome diameter is influenced by terpene concentration. An increase in terpene content was associated with a corresponding increase in vesicle size. For example, invasomes formulated with 0.5% terpenes showed an average size of approximately 93.0 nm, whereas those containing 1% terpenes exhibited a larger mean diameter of about 124 nm[35].In addition to concentration, the molecular characteristics of the terpene also affect vesicle size. Prasanthi *et al.* observed that both the molecular weight and type of terpene contributed to variations in invasome dimensions. Invasomes prepared with nerolidol (molecular weight 222 g/mol) were significantly larger, ranging between 11 and 13 µm. In contrast, nimesulide-loaded vesicles formulated with citral, limonene, and cineole demonstrated smaller diameters of approximately 194 nm, 216 nm, and 244 nm, respectively[41],[42].These findings indicate that both the concentration and molecular properties of terpenes play important roles in determining the physicochemical characteristics of invasomal formulations.

1.2.2.3 Effect of Terpenes on the Shape of Invasomes

Cryo-transmission electron microscopy (cryo-TEM) analysis has shown that the presence of terpenes affects the structural characteristics of invasomes. In addition to typical spherical vesicles, formulations containing terpenes displayed irregular and deformed shapes[36].According to Dragicevic-Curic *et al.,* invasomes prepared with 0.5% terpenes were mainly spherical or oval in shape and consisted largely of unilamellar and bilamellar vesicles. However, increasing the terpene concentration to 1% resulted in a higher proportion of distorted vesicles, indicating enhanced membrane flexibility and deformability[36].

1.3 Synergistic Effects

Phospholipids, ethanol, and terpenes work together to improve drug permeation through the skin[36]. During the penetration process, invasomes may partially break down within the epidermal layers, releasing their components. The liberated phospholipids and terpenes contribute to lipid fluidization and enhance drug diffusion across the stratum corneum. Ethanol further increases the fluidity of intercellular lipids and supports the movement of highly deformable vesicles through the skin barrier[43],[44].Verma *et al*. observed that invasomal formulations significantly enhanced the transdermal delivery of cyclosporine A when compared to simple ethanolic drug solutions. Similarly, Dragicevic-Curic *et al*. reported that increasing terpene concentration, particularly to 1%, along with the combined action of ethanol and terpenes, markedly improved temoporfin permeation[36]. Overall, these studies indicate that the combined effects of phospholipids, ethanol, and terpenes create a synergistic mechanism that enhances skin penetration more effectively than conventional liposomal systems[36],[45],[46].

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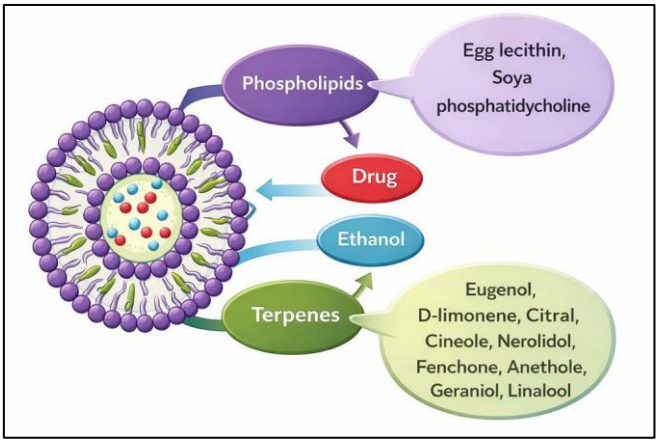

Figure 4. Composition of Invasomes

1.4 Penetration Mechanism of Invasomes

The enhanced permeability of invasomes is primarily attributed to the combined action of ethanol and terpenes. These components promote vesicle deformability, disturb the lipid organization of the stratum corneum (SC), and function as effective penetration enhancers. According to Dragicevic-Curic *et al*., once invasomes reach the skin surface and begin to penetrate, a fraction of the vesicles may disassemble within the epidermis. This process releases terpenes and phospholipid components, which contribute to lipid fluidization and facilitate deeper drug diffusion through the SC.

Due to their nanoscale size and high flexibility, some invasomes are able to remain intact during penetration and pass through the SC without losing their structural integrity. Verma *et al.* suggested that intact vesicles may enter the skin via follicular pathways or through small hydrophilic channels present within the intercellular regions of the SC. Generally, smaller and more deformable invasomes show greater ability to penetrate deeper layers of the skin while maintaining vesicular structure. However, partial disintegration of some vesicles after crossing the SC has also been observed[47,34] (Figure 5). These characteristics highlight the strong potential of invasomes as efficient carriers for transdermal drug delivery.

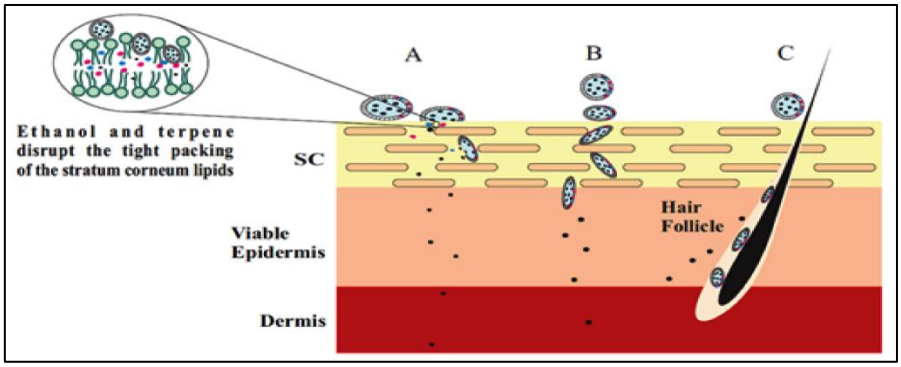

Figure 5. Penetration mechanism of invasomes through the stratum corneum (SC). (A) Enhanced penetration, (B) Intact penetration and (C) Trans-appendageal penetration

2. Materials and Methods

2.1 Preparation methods

2.1.1 Mechanical dispersion technique

To prepare invasomes, the drug and selected terpenes or terpene mixtures are first dissolved in an ethanolic phospholipid solution. This mixture is vortexed for approximately 5 minutes to ensure proper mixing, followed by sonication for another 5 minutes to obtain a clear and homogeneous solution. Subsequently, phosphate-buffered saline (PBS, pH 7.4) is slowly added dropwise using a syringe under continuous stirring for an additional 5 minutes to form the final invasomal formulation[48,49].

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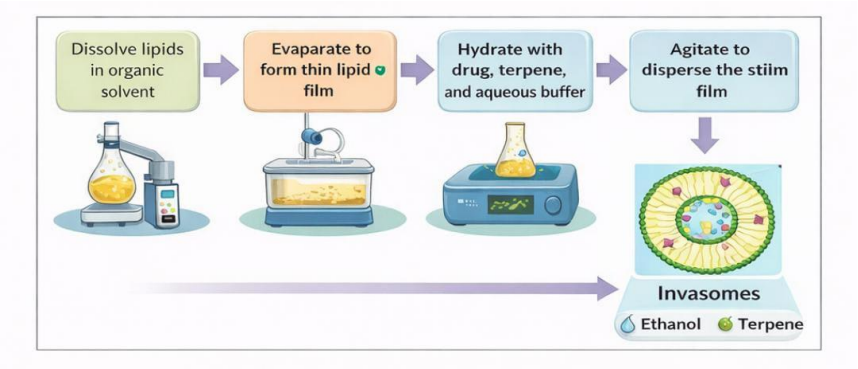

Figure 6. Mechanical dispersion technique

2.1.2 Thin film hydration method:

Invasomes may also be prepared using the conventional thin-film hydration technique. In this method, phospholipids are dissolved in an ethanolic solution containing a small proportion (2% v/v) of methanol and chloroform. The organic solvents are then evaporated using a rotary evaporator at 50°C while gradually decreasing the pressure from 500 to 1 mbar, resulting in the formation of a thin lipid film on the flask wall. The film is further dried under vacuum (1 mbar) for 2 hours at room temperature and subsequently purged with nitrogen gas to remove any residual solvent. For invasome formation, the dried lipid film is hydrated for approximately 30 minutes at the lipid phase transition temperature using phosphate buffer (pH 7.4) containing ethanol and terpenes. Alternatively, hydration can first be performed with phosphate buffer (pH 7.4), followed by the addition of ethanol and either a single terpene or a terpene combination after the system has cooled to room temperature[50,51].

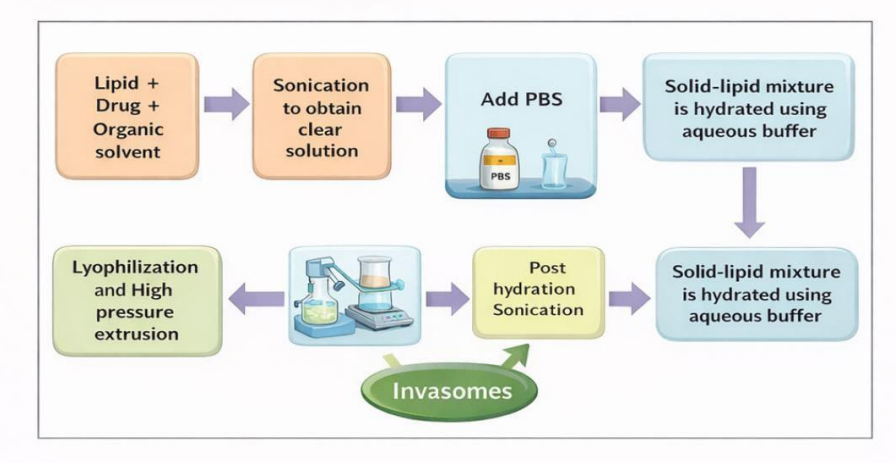

Figure 7. Thin film hydration technique

2.2 Characterization of invasomes

- Entrapment Efficiency
- Surface Morphology
- Drug Content
- Vesicular size
- *Ex Vivo* Permeation Studies
- Stability Studies

2.2.1 Entrapment Efficiency

Entrapment efficiency was evaluated using the ultracentrifugation technique. Briefly, 1 mL of the invasomal formulation was subjected to centrifugation at 15,000 rpm for 15 minutes at 4°C, and this process was repeated for two cycles using Eppendorf tubes. After centrifugation, the clear supernatant containing the unentrapped (free) drug was carefully collected and analyzed to determine the amount of free drug present. The percentage of drug encapsulation was then calculated indirectly based on the measured concentration of free drug using the appropriate formula.

$$\text{Entrapment Efficiency (\%)} = \frac{total\ drug - free\ drug}{total\ drug} \times 100$$

2.2.2 Surface Morphology

A small quantity of the formulation was placed on a clean glass slide and allowed to dry at room temperature. After drying, the sample was coated with a thin layer of gold using a Polaron E5100 sputter coater (Watford, UK) and subsequently analyzed by scanning electron microscopy (SEM) to evaluate its surface morphology.The optimized invasomal formulation was stored in a 10 mL glass vial for a duration of one month under two storage conditions: room temperature and refrigerated conditions (4–8°C). Throughout the storage period, samples were periodically examined for changes in physical appearance and entrapment efficiency[52].

2.2.3 Drug Content

The drug content in invasomal formulations can be accurately measured using a UV–visible spectrophotometer. For greater sensitivity and precision, high-performance liquid chromatography (HPLC) may also be employed for quantitative analysis. These analytical techniques provide reliable methods for ensuring the uniformity and quality of invasome formulations, thereby supporting their development and optimization for various therapeutic applications[53].

2.2.4 Vesicular Size and Shape

The morphological characteristics of invasomes can be examined using scanning electron microscopy (SEM) and transmission electron microscopy (TEM). In addition, vesicle size distribution and zeta potential can be determined using photon correlation spectroscopy and dynamic light scattering (DLS), which provide information regarding particle size and surface charge[54].

2.2.5 Ex-vivo Permeation studies

The osmolarity of the invasomal formulations was not evaluated using a Franz diffusion cell apparatus, as the Franz diffusion cell is used for *ex vivo* permeation studies, not for osmolarity determination. For the *ex vivo* permeation study, a Franz diffusion cell apparatus was used. The diffusion cell had a receptor compartment volume of 20 mL and an effective diffusion area of 2.0 cm^2. During the experiment, the skin sample was mounted between the donor and receptor compartments with the stratum corneum facing upward toward the donor side, where the invasomal formulation was applied. The assembly was covered with a cap to maintain controlled experimental conditions. The receptor compartment was filled with 20 mL of phosphate-buffered saline (pH 7.4) and maintained at 37°C throughout the study. At predetermined time intervals, aliquots were withdrawn from the receptor medium and replaced with an equal volume of fresh buffer to maintain sink conditions. The collected samples were analyzed using a UV spectrophotometer to quantify the drug content[3].

2.2.6 Stability Studies

The physical stability of the optimized formulation was assessed to evaluate potential drug leakage from the vesicles. Two 10 mL ointment tubes containing the invasome gel were tightly sealed and stored under different temperature conditions. One tube was refrigerated at 4–8°C, while the other was maintained at room temperature (27–30°C).The samples were examined weekly for one month to monitor any variations inviscosity, drug content, or overall physical characteristics. This evaluation provided important information about the formulation's stability and shelf life under different storage conditions[55].

2.3 Applications of Invasome

In this section, we have enumerated several applications of invasomes. An overview of various studies on the therapeutic applications and skin permeability enhancement of invasomes is given in Tables 1 and 2, respectively.

Table 2. Therapeutic application of invasomes.

Drug	Applications	Type of study	Study Outcomes	Ref.
Ferulic acid	Antioxidant effect	Excised human skin	Ethosomes are better vesicular carriers for the delivery of ferulic acid into the skin than invasomes	56
Avanafil	Treatment of erectile dysfunction	Excised abdominal rat skin	Optimized invasomal film improved the bioavailability and transdermal permeation of Avanafil	57
Curcumin	Anti-inflammatory, antioxidant, and anticancer activity	Shed snake skin	Physicochemical characteristics of the formulations influenced by terpene and Tween 20	58
Curcumin	Anti-inflammatory, anti-carcinogenic, Etc.	Excised rat skin	Invasome with 0.5% limonene improved intradermal penetration of curcumin	57
• Idebenone • Azelaic acid	Antioxidant/anticancer, anti-acne	Excised human skin	LeciPlex exhibited higher permeation of idebenone and invasomes exhibited higher permeation of azelaic acid	59
Temoporfin	Photodynamic therapy (a pilot study)	Mice skin	Temoporfin invasomes containing a 1% terpene mixture decreased tumor size significantly by photodynamic therapy compared to control groups	60
Temoporfin	Photodynamic therapy	Human epidermoid tumor cell line A431	In the A431 cells temoporfin loaded invasomes were more cytotoxic	52
Temoporfin	Photodynamic therapy	Abdominal human skin	Invasomal formulation with 1% mixture of terpenes exhibited a significantly enhanced deposition of temoporfin in the SC compared to liposomes	35

Table 3. Enhanced skin permeability of invasomes.

Drug	Applications	Type of study	Study Outcomes	Ref.
Carboxyfluorescein Temoporfin	Hydrophilic model drug, lipophilic model drug	Excised human skin	Ethosomes and invasomes increased the delivery of hydrophilic drug, for example carboxyfluorescein, into the deep layers of skin	61
Fluorescent label	Tracking of invasomes	Excised human forearm skin	Strong spectroscopic evidence shows deep penetration of intact invasomes in the SC	7
Nitroxide TEMPO	Measuring the antioxidative capacity	Excised human skin/ excised porcine skin	Invasomes improved measurement times of antioxidative capacity by two-fold	62
3-Carboxy 2,2,5,5 tetramethyl-1 pyrrolidinyloxy (PCA)	Spin-labeling compound	Excised porcine skin	PCA permeation was improved 2.5-fold for CMS and two-fold for invasomes in comparison with PCA solution	46
Temoporfin	Photosensitizer	ESR measurements	Terpenes improved the fluidity of the bilayers, whereas temoporfin reduced the fluidity. Therefore, invasomes represent vesicles with excessive membrane flexibility	34
Calcein Carboxyfluorescein	Low-molecular weight hydrophilic model drugs	Excised human skin	Calcein penetration improved two- and seven fold by transfersomes and invasomes, respectively	63

2.4 Therapeutic Efficacy Enhancement

Invasomal technology significantly enhances therapeutic outcomes by promoting improved drug penetration across the stratum corneum and increasing drug accumulation at the intended site of action. The combined effect of ethanol and terpenes enhances vesicle flexibility and disrupts skin lipid organization, enabling the drug to reach deeper layers of the epidermis and dermis. Compared with conventional topical and transdermal systems, this enhanced permeation leads to improved bioavailability and a stronger pharmacological effect.Moreover, invasomes provide sustained and controlled drug release, helping to maintain therapeutic drug levels over an extended period. This characteristic is particularly advantageous in the management of chronic skin disorders and inflammatory conditions that require prolonged treatment. Several *in vivo* studies have demonstrated that invasomal formulations exhibit superior efficacy compared to traditional gels and standard liposomal preparations, ultimately reducing dosing frequency and improving patient adherence.

2.5 Safety and Biocompatibility

Safety and biocompatibility play a vital role in the design of transdermal drug delivery systems. Invasomes are mainly formulated using biodegradable and biocompatible materials, including phospholipids, ethanol, and naturally sourced terpenes. When used at appropriate concentrations, these components are generally considered safe and produce minimal skin irritation.Recent investigations have indicated that topical application of invasomal formulations does not result in significant erythema, edema, or structural skin damage. Furthermore, targeted drug delivery through invasomes limits systemic absorption, thereby decreasing the likelihood of systemic adverse effects. Findings from cytotoxicity and skin irritation assessments further support the safety and suitability of invasomes for prolonged topical and transdermal use.

2.6 Future Perspectives

Nanotechnology is expected to play a major role in improving vesicular drug delivery systems in the future. Designing topical and transdermal formulations requires both scientific knowledge and formulation skills. Invasomes are promising vesicular carriers because they are well tolerated and show better skin penetration.Advanced lipid-based vesicles such as elastic, flexible, and deformable systems can deliver many types of drugs and help treat different diseases. Invasomes can carry both hydrophilic (water-soluble) and lipophilic (fat-soluble) drugs. Their ability to control drug release makes them suitable for future innovative drug delivery systems.Researchers are still working to improve the stability of invasomes to prevent drug leakage, lipid oxidation, and removal by the body's defense systems. Improvements in ultra-flexible and deformable invasomes may help enhance the delivery of bioactive molecules through the skin and make transdermal therapy more effective.

3. Conclusion

Invasomal systems represent an innovative approach to addressing the shortcomings of traditional transdermal drug delivery methods. By facilitating enhanced skin permeation, increasing drug bioavailability, and providing controlled as well as site-specific release, invasomes help overcome the challenges associated with limited drug penetration and suboptimal therapeutic response.Although certain issues such as formulation stability and regulatory requirements remain, continuous progress in nanotechnology and pharmaceutical formulation techniques is likely to broaden their scope in clinical and therapeutic applications. Future investigations should emphasize scale-up production, comprehensive safety assessment, and clinical validation to maximize the therapeutic potential of invasome-based drug delivery systems in contemporary medicine.

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Author contributions

All authors contributed equally to this work. The authors have contributed significantly in the conception, writing, and revision of the manuscript.

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Conflict of interest

None to declare

Ethics approval

None to declare

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