

Nanotechnology-Based Drug Delivery Systems for Dermatophytosis: Current Progress and Future Directions

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ABSTRACT

One of the most common superficial fungal infections in the world, dermatophytosis affects almost 25% of people worldwide and presents a serious public health concern because of its rising recurrence rate, lengthy treatment duration, developing antifungal resistance, and low patient compliance. Traditional topical and systemic antifungal treatments frequently have poor skin penetration, low bioavailability, systemic side effects, and insufficient retention at the infection site, all of which lead to less than ideal treatment results. By improving medication solubility, stability, targeted administration, controlled release, and penetration through the stratum corneum, nanotechnology-based drug delivery systems have recently surfaced as viable substitutes that can get over these restrictions. This study critically assesses recent developments in nano-enabled antifungal formulations while providing a thorough summary of the state of knowledge on dermatophytosis, including its epidemiology, pathogenic organisms, pathophysiology, clinical symptoms, and current therapeutic methods. The formulation features, mechanisms of improved skin delivery, therapeutic performance, and recent preclinical advancements of lipid and polymer-based nano-carriers such as liposomes, ethosomes, transfersomes, niosomes, solid lipid nanoparticles, nanostructured lipid carriers, phytosomes, dendrimers, nanogels, and polymeric nanoparticles are highlighted. The benefits, present difficulties, obstacles to translation, and prospects for the future of these cutting-edge distribution systems are all covered in detail in the review. All of the research that is now available shows that topical delivery via nanocarriers greatly increases antifungal activity, drug retention in infected tissues, bioavailability, and patient compliance while reducing systemic toxicity. Transforming these cutting-edge nanotherapeutic systems into successful clinical interventions for the therapy of dermatophytosis will require ongoing optimization, consistent clinical evaluation, scalable manufacturing, and regulatory harmonization.

Keywords: Dermatophytosis; Nanotechnology-based drug delivery; Topical antifungal therapy; Lipid nanocarriers; Targeted transdermal drug delivery

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INTRODUCTION

Dermatophytosis is a superficial fungal infection caused by filamentous fungal species (dermatophytes) that are members of the three anamorphic genera *Trichophyton*, *Microsporum*, and *Epidermophyton*. Affecting 20–25% of people worldwide, it is the most prevalent superficial fungal infection.

The stratum corneum of the epidermis and the keratinized tissues that comprise it, including human and animal skin, nails, and hair, can be penetrated by dermatophytes, a group of closely related fungus [1]. These are special class of keratinophilic fungi can live on keratin-rich substances found in soil or the skin of humans and animals. The resistance of dermatophyte species to antifungal drugs has increased significantly as the number of people with immune system deficiencies has increased. Immunocompromised patients who receive prolonged prophylaxis with

antifungal agents cause the emergence of resistant strains of dermatophytes. Unfortunately, the extensive use of antifungals to treat these infections has resulted in drug resistance. Thus, medication resistance in pathogenic fungi, particularly the dermatophyte, is becoming increasingly important [2]. The aim of this paper is to provide an analysis of the current state of nanotechnology-based drug delivery systems in treating dermatophytosis, giving an objective and critical assessment of the methods that currently exist and their possibilities, strengths and weaknesses with the goal of outlining future directions in treatment of this disease.

1.1 Biology

Every pathogenic dermatophyte has a unique morphological characteristic. On the basis of development, colony morphology and Conidia found in it, dermatophytes can be described as follows:

Epidermophyton spp. usually has yellowish-green colonies that are folded and have a suede-like feel; they can be bleached to become sterile and floccose. Numerous clavate macro conidia, typically smooth, It produces 8-59 septa, walls that are thin to moderately thick, with diameters of 20-60 by 4-13µm. Micro conidia are generally absent.

Microsporum spp. possesses yellowish-orange colouring and dusty, granular colonies with a cottony surface. It produces fusiform, pyriform, or cylindro-fusiform macroconidia with echinulate or verrucous walls and 1-15 septa measuring 1-160 by 6-25 µm. They are moderately thick to thick. It displays clavate or sessile microconidia that are carried laterally either in clusters or directly on the hyphae.

Trichophyton spp. appears with different macroscopic features that vary from species to species, including as hairy, cottony, grainy, and cerebriform colonies. The underside of colonies may have reddish to brownish tint. If there are macro conidia, they have a smooth, frequently thin wall with 1-12 septa that can be clavate to fusiform and can be found alone or in clusters. They are between 8 and 86 by 4 and 14 µm in size. They also produce micro conidia, which are sessile, globose, clavate, or fusiform, and can be more numerous than macro conidia. They are borne laterally, either directly on the hyphae or in pedicels [3].

1.2 Clinical forms of dermatophytosis

The inflammatory host response and keratin degradation work together to generate dermatophytosis, which has a very diverse clinical appearance. A number of factors influence the range of clinical manifestations, including the host's immunological state, the location and keratinization of the affected area, and the causative fungus (zoophilic fungi cause a more inflammatory reaction than anthropophilic dermatophytes) [4]. Dermatophytosis could be classified as follows based on the body part that is impacted and the keratinisation at the infection site:

Tinea corporis: It usually affects exposed glabrous skin, such as the neck, chest, shoulders, and limbs; it is rarely found on the legs. It is never found on the scalp, beard, feet, or hands, but an examination of the latter may reveal the infection's cause. *M. canis*, *T. rubrum*, *T. mentagrophytes*, *T. tonsurans*, and *E. floccosum* are the etiologic agents; however, other agents, including *M. audouinii*, *T. verrucosum*, *M. aenigmaticum*, *M. praecox*, and a novel species of *M. gypseum* complex, have been discovered infrequently [3]. An annular plaque with variable erythema and a noticeable edge (kerion) is the hallmark lesion of dermatophyte infection on the trunk or limbs. Although this edge is where scaling is most noticeable, appearance varies by organism and host. Particularly in the tropics, *T. rubrum* is linked to persistent, mildly inflammatory *tinea corporis* [5].

When a cutaneous dermatophyte infection, like *tinea corporis*, is subjected to occlusion or recurrent superficial trauma, like shaving the skin, follicular tinea typically develops. An erythematous plaque with follicular papules or pustules may be the initial appearance of the eruption. In contrast to classic *tinea corporis* (also known as "ringworm"), erythema is typically deeper. Majocchi's granulomas are usually found on the legs and are caused by *T. rubrum*. They are often more infiltrative and can occasionally manifest as a soft nodule with pustular plaque or an inflammatory nodule. When dermatophyte diseases like *tinea corporis* or *tinea manuum* are treated with topical corticosteroids, the fungus may more fully penetrate the follicles.

Tinea imbricata: It is *Trichophyton concentricum* that causes *T. imbricata*. The skin lesions are characterized by concentric, scale-like, lamellar plaques that resemble erythema gyratum repens [6].

Tinea corporis gladiatorum: Often seen on the arms, head, and neck of athletes who typically participate in sports like wrestling. The etiological agent is *Trichophyton tonsurans* [7].

Tinea incognito: A kind of *tinea corporis* called *tinea incognito* has changed appearance when mild to heavy corticosteroids are applied. A diffuse erythema with follicular papules and pustules is typically the result of the lack of annular scaling and distinct edges. These are brought on by the fungus's intracellular invasion [8].

Tinea cruris: *Tinea cruris* and *genitalis* are the names for the dermatophytic infection of the genitalia and inguinal folds [9]. *Tinea cruris* is the term for the dermatophyte-caused "jock itch" that affects the groin region. Although *tinea cruris* primarily affects the proximal and medial thighs, it can also spread to the buttocks and abdomen [10]. *Tinea cruris* can spread posteriorly to the intergluteal gap and is more prevalent in men. A prevalent type of ringworm that affects women around the waist may damage a significant portion of the skin surrounding the hip girdle [5]. This highly contagious disease is typically contracted by coming into contact with contaminated towels or by touching contaminated surfaces in showers, bathrooms, or hotel rooms. The same fungus that causes *tinea cruris* also causes *tinea pedis* in many people [11]. Men are typically affected by this skin disorder, which is the second most common dermatophytosis [12]. Between 20 and 25 percent of people worldwide suffer from dermatophytosis [2]. In patients with pre-existing *tinea pedis*, autoinoculation is typically the cause of *tinea cruris*. To lower the chance of recurrence, concurrent *tinea pedis*, if present, should be treated [13].

Tinea faciei: "Tinea corporis of the glabrous skin of the face" is what *tinea faciei* stands for. The redness and scaling border are usually less evident, even if the lesions may display the traits that define *tinea*

corporis. There might be multiple patches. Therefore, it is important to consider different dermatoses such as seborrheic dermatitis, discoid lupus, rosacea, contact dermatitis, etc., as the lesions may not always be indicative of a dermatophyte infection. This misleading characteristic supports the disease's differentiation from *tinea corporis*. Although geographical locations have an impact on the causative agents, the illness typically results from an extension of an infection elsewhere on the body or from a zoophilic reservoir in pets and animals [4]. *Tinea faciei* is mostly visible in the area that is not bearded. Of all surface fungal infections, *tinea faciei* is the cause of about 19%. It affects children who have dermatomycoses. Women are affected more frequently than men. On the face, they usually appear as red hives with small patches, elevated bumps, and a chin and upper lip. Burning and itching are typically the warning signs, and they are brought on by exposure to sunlight. The most common *T. faciei* agents are *T. tonsurans*, *T. verrucosum*, *T. mentagrophytes*, *M. canis*, and *T. rubrum* [14].

***Tinea pedis* (athlete's foot):** Dermatophytes are the main cause of athlete's foot, also known as *tinea pedis*, which is a superficial skin infection of the feet and toes. It is among the most prevalent types of dermatophytosis. Interdigital, moccasin, and vesicobullous are the three clinical signs of *tinea pedis*. The maceration, scaling, and fissure of the interdigital regions—particularly the 4/5-toeweb—distinguish the most common kind, interdigital *tinea pedis*. *Trichophyton rubrum* and *T. mentagrophytes* are the most common culprits that cause infections. The simplest type of interdigital *tinea pedis* is called "dermatophytosis simplex." Because the dermatophytes have already disrupted the skin barrier, secondary bacterial infections are common. The phrase "dermatophytosis complex" describes the extremely inflamed, macerated skin brought on by an excess of microbes.

***Tinea capitis*:** An infection of the hair and scalp that mainly affects newborns and teenagers. Clinical signs can vary greatly, ranging from minor peeling lesions to severe lesions like pustules and vesicles [15].

***Onychomycosis*:** Nail dermatophyte infections are uncommon in the tropics.

Usually from the bottom, the nail plate's lateral surfaces and distal border are invaded. *Onycholysis* varies in severity, and the affected nail thickens and turns opaque.

1.3 Etiology

Even though dermatophytosis is a global problem, the geographic distribution and self-virulence of individual dermatophyte species can vary. Poor living conditions, children's interaction patterns, and poor health-seeking behavior are some of the factors contributing to the high frequency and chronic occurrences of dermatophytosis in developing countries. Although poverty and overcrowding are important underlying social determinants, these disorders cannot be differentiated by ethnicity or socioeconomic status. *Trichophyton rubrum*, *Trichophyton tonsurans*, *Trichophyton interdigitale*, *Trichophyton mentagrophytes*, *Microsporum canis*, and *Epidermophyton floccosum* are the most common dermatophyte species that infect humans out of approximately 40 species. [16].

1.4 Signs and symptoms

Among the common signs of dermatophytosis are burning and itching. On a background of red, scaling lesions with raised borders, the active edge of the infected region has pustules and vesicles in addition to maceration [10]. Affected areas are indicated by red, tan, peeling, cracking, or rippling brown skin [14].

1.5 Pathophysiology

The three genera that comprise the majority of dermatophytes are *Trichophyton*, *Microsporum*, and *Epidermophyton*. They flourish because of their keratinophilia. Mostly on areas that are high in keratin, such as the skin, hair follicles, and nail beds. Adhesion to the keratinized surface is a critical step in the dermatophytic cycle. Tissues made by fungus spores called arthroconidia, which develop before the segmentation of hyphae. Numerous adhesion molecules aid in the fungal attachment process to the host cell. The microconidial surface of *T. rubrum* and *T. mentagrophytes* has carbohydrate-specific adhesins that allow them to stick to the membrane of the host cell. The peptidases that *M. canis* secretes, metalloproteases, dipeptidyl, and subtilisin, are necessary for the host adherence process.

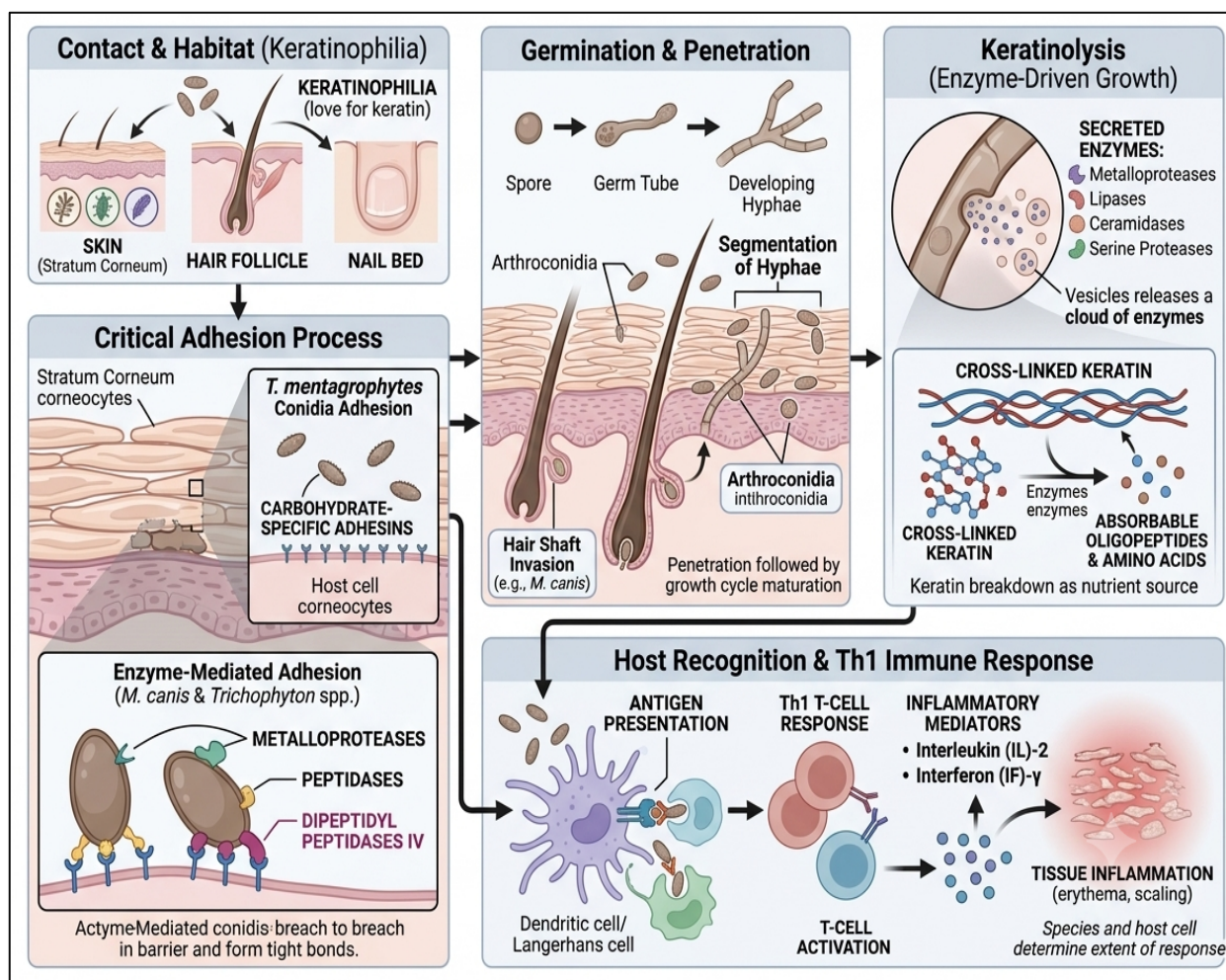


Figure 1: Pathophysiology of dermatophytosis

The unique type of dipeptidyl peptidases IV secreted by *M. canis* and *Trichophyton spp.* have also been examined in connection with the adhesion process. Adhesion to the host cell is followed by penetration into the SC. The hyphae that arise from the arthroconidia are responsible for initiating the penetration into the host cell's SC. Furthermore, the hyphae complete the dermatophyte growth cycle by maturing into the arthroconidia following a 7-day incubation period. Once inside the keratinized tissues, dermatophytes release several keratinases: metalloproteases, lipases, ceramidases, and serine proteases. The cross-linked keratin network is broken down and changed into absorbable oligopeptides or amino acids by these enzymes.

Proteases, which are enzymes generated by dermatophytes, are the main source of immune system activation reactions. Th1-type adaptive immune

Table 1: Oral and topical Anti-Dermatophytic agents

Drugs	Disease	Mechanism of action	References
Morpholine derivatives			

responses, which promote pro-inflammatory mediators, make up the majority of immunological responses. Examples include interleukin (IL)-2 and interferon (IF)- γ . The dermatophyte species and the physiological state of the host cell determine the extent and strength of the immune response [17].

2. Available treatment of dermatophytosis

The topical drugs that may be helpful in treating dermatophytosis are included in Table 1, along with the indications for topical treatment of dermatophyte infections. The doctor should consider a number of factors when prescribing an antifungal or treatment plan for dermatophytosis, such as the patient's personal preferences, the dermatophyte species that caused the infection, the patient's underlying conditions, clinically proven efficacy, treatment duration, cost, and the long-term assessment's percentage of recurrence.

Amorolfine	Tineacorporis	Inhibition of C-14 reductase and C8 isomerase	[11]
Allylamines and benzylamine derivative			

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Naftifine	Tineacurris	Inhibition of squaleneepoxidase	[10],[18]
Terbinafine	Tineacurris , Tineaunguium, Tineabarbae, Tineafaciei , Tineapedis		
Butenafine	Tineacorporis, Tineacurris , Tineapedis		
Azole derivatives			
Clotrimazole	Tineacorporis, Tineacurris , Tineapedis	Inhibition of Lanosterol 14 α demethylase	[15]
Sertaconazole	Tineacorporis, Tineacurris		
Eberconazole	Tineacorporis, Tineacurris , Tineapedis		

Luliconazole	Tineacorporis, Tineacuris , Tineapedis		
Itraconazole	Tineacorporis, Tineacuris , Tineapedis		[15]
Miscellaneous compounds			
Griseofulvin	Tineacorporis, Tineapedis , Tineacuris	Inhibition of microtubule aggregation	[15]
Tolnaftate	Tineacorporis, Tineapedis , Tineacuris , Tineafaciei	Inhibition of squaleneepoxidase	[15]
Hydroxypyridone derivative			
Ciclopirox	Tineacorporis, Tineapedis , Tineacuris , Tineaversicolor.	Chelation of trivalent metal cations Inhibition of metal dependent enzymes – catalase, peroxidase	[15]

3. Novel drug delivery system for topical treatment of dermatophytosis

The primary challenges facing the antifungal medications now available on the market include high toxicity, subpar pharmacokinetic properties, and restricted clinical efficacy. Combination therapy also increases the risk of adverse drug interactions and side effects. In this regard, nanotechnology-based techniques exhibit improved inhibitory efficacy against fungal infections at lower dosages. Nanocarriers also aid in the accurate distribution of antifungal drugs. Nanocarriers are better than conventional dose forms because of their unique optical, electrical, mechanical, or chemical

Figure 2: Nanocarriers that can improve therapeutic outcomes in the management of Liposomes

Liposomes are self-forming nanostructures that are created when lipid molecules are organized in an aqueous solution [11]. These are tiny vesicles with an

characteristics. Nanotechnology has a role in the creation of tools and materials. phospholipid vesicles, such as ethosomes, transethosomes, liposomes, and transfersomes; metal oxide nanoparticles, silver nanoparticles (AgNPs), carbon nanotubes (CNTs), solid lipid nanoparticles (SLNs), solid phospholipid vesicles (such as spanlastics and niosomes), nanostructured lipid carriers (NLCs), nanoemulsions, and polymeric nanoparticles (such as chitosan-based nanoparticles); and dendrimers are two of the numerous varieties of nanocarriers that are employed as drug delivery systems (DDS) to treat fungal illnesses [19].

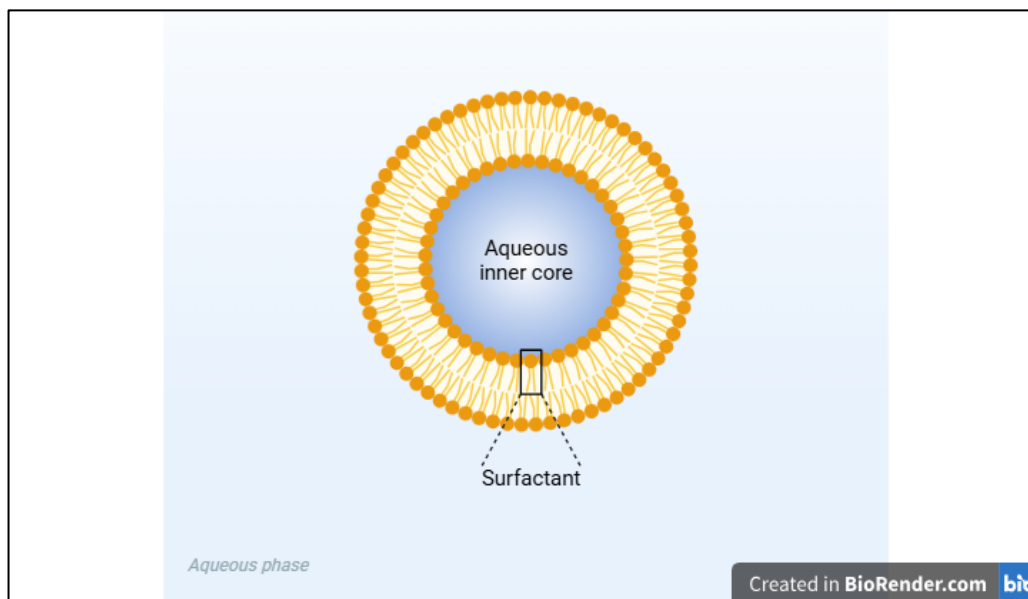
dermatophytosis

‘aqueous core surrounded by one or more lipid-based outer shells arranged in a bilayer configuration [20]. Because of their localizing qualities, liposomes can improve penetration through the stratum corneum,

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lessen systemic effects, and get past several obstacles to external medicine administration. By applying medicine to a specific area of the skin, dermal administration maximizes its local advantages while avoiding systemic negative effects [21]. Ravika Nanda et al. developed the formulation of fluconazole-loaded elastic liposomes for the treatment of keratomycosis using the thin film hydration

173.6 $\pm$ 5.9. 91.35 $\pm$ 1.4 was the calculated cumulative drug release. The calculated polydispersity index was 0.303 $\pm$ 0.03 and the estimated entrapment efficiency was 95.2%. In addition to demonstrating exceptional entrapment efficiency, they have demonstrated that fluconazole-loaded elastic liposomes function as a vehicle for the safe and efficient delivery of the medication [22].



approach. The vesicle was found to have a smooth surface, a spherical shape, and an optimal batch size of

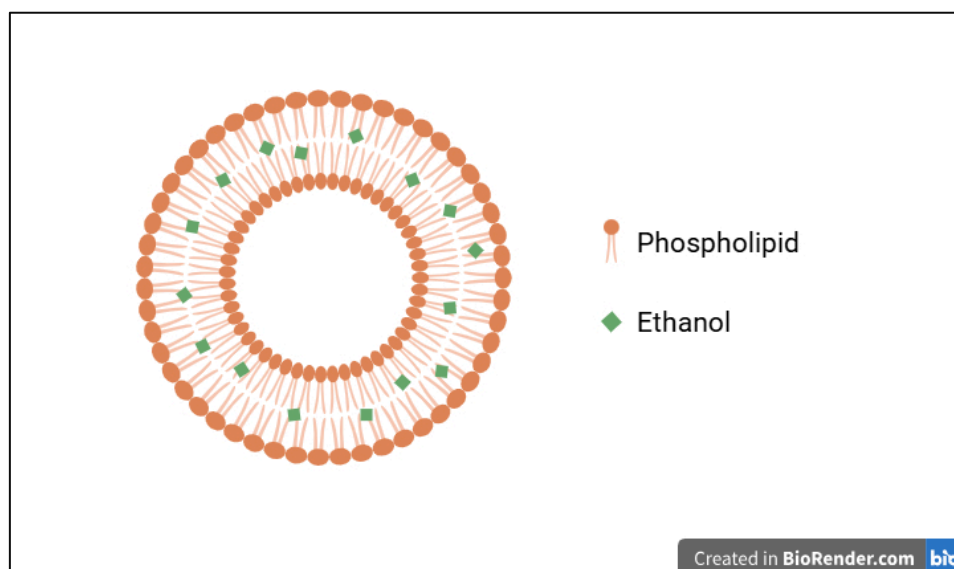
Figure 3: Liposomes for drug delivery

Ethosomes

Similar to liposomes, ethosomes contain a significant amount of ethanol. Ethosomes are incredibly soft vesicles that include water, ethanol, and phospholipids. The skin is easily pierced by these systems [20].

One of the most recent innovative itraconazole-loaded ultra-deformable transethosomes was created by K.K.

Mishra et al. For the ICZ-loaded TEs, the average vesicle size, polydispersity index, and zeta potential were 207.4 $\pm$ 2.23 nm, 0.131 $\pm$ 0.027, and -21.96 mV, respectively. The drug entrapment efficiency was 72.6 $\pm$ 0.6%. Transethosomes contain itraconazole in an amorphous condition. Over the course of 24 hours, ICZ-loaded TEs gel showed a consistent ex-vivo penetration of ICZ. They demonstrate the presence of



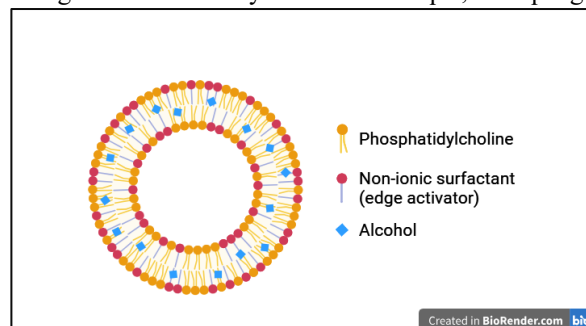
Nanotechnology-Based Drug Delivery Systems for Dermatophytosis: Current Progress and Future Directions transthesomes in the skin's deeper layers, and an in-vivo investigation found that TEs loaded with ICZ were a promising antifungal candidate against *Trichophyton* species [23].

Figure 4: Ethosomes for drug delivery

Transfersomes

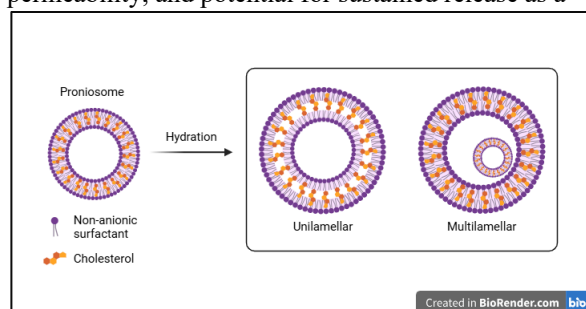
The structural characteristics and methods of preparation of transfersomes are comparable to those of liposomes. Their ability to deform and their mode of skin penetration, however, set them apart from liposomes. Phospholipids and edge activators are added to provide this improved deformation capability [17].

Using a thin-film hydration technique, Zhiqiang



Niosomes

The sole difference between liposomes and niosomes is that non-ionic surfactants are used in place of phospholipids [11]. Niosomes, which are self-assembled non-ionic surfactant-based vesicles, have recently attracted a lot of attention in the areas of topical, transdermal, and targeted drug delivery. This is due to the fact that these vesicles are inexpensive, simple to make, high compatibility, chemically stable, biodegradable, and have low toxicity (since they are non-ionic). Niosomes' enhanced solubility, permeability, and potential for sustained release as a



Solid lipid nanoparticles

The medicine is contained within a solid lipid core matrix in solid lipid nanoparticles, which are transporters [11]. These nano-lipid carriers transport the active drug throughout a lipid core matrix. These are nanoparticle-imprinted matrices based on lipids and surfactants. Solid lipid nanoparticles can be made by high homogenization or microemulsion preparation. The oil phase of solid lipid nanoparticles (SLNs) is w/o emulsion. Because the lipids used by SLNs are physiologically equivalent, they are biocompatible, which reduces their risk of toxicity. Lipid particles can come into close contact with the

Cheng et al. prepared a fluconazole-embedded transfersomal gel for the treatment of fungal infection. They recorded optimized batch entrapment efficiency of $89.92\% \pm 0.20\%$ to $97.28\% \pm 0.42\%$, in vitro drug diffusion of $64\% \pm 1.56\%$ to $85\% \pm 2.05\%$, particle size of 397 ± 2 nm, PDI 0.38 ± 0.05 mV, 0.43%, and they demonstrated that Transfersomes are a new way to overcome solubility issues and improve therapeutic results [24].

Figure 5: Transfersomes for drug delivery

local reservoir are further benefits [25].

Innovative Ketoconazole For the treatment of fungal infections, Loaded Niosomal Gel with Carbamideone is a newly developed, innovative composition. It was created by Prajitha Biju and colleagues, who found that optimized niosomes had a 98.38% drug entrapment efficiency and a vesicle size of 275 nm. Improved skin conditions and a prolonged in vitro drug release have been reported. It showed promise as a carrier for the delivery of drugs topically to prevent fungal infections [26].

Figure 6: Niosomes for drug delivery

stratum corneum due to their reduced size, which facilitates controlled release and drug penetration through the skin. By forming a protective layer on the skin, their makeup stops water from evaporating [27]. Chitosan-covered by addressing the solubility and bioavailability concerns of griseofulvin made using the hot melt sonication approach, N Sreeharsha et al. created griseofulvin-loaded SLNs for antifungal efficacy. They measured the zeta potential at -34.8 mV, the average particle size at 56.87 nm, and the drug loading (DL) and encapsulation efficiency (EE) at 94.81% and 58.06%, respectively. For encapsulation and long-term drug delivery, they have shown that

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SLNs work well. Griseofulvin-loaded, chitosan-coated SLNs had a bioavailability that was roughly 1.7–2.0 times higher than that of a typical formulation [28].

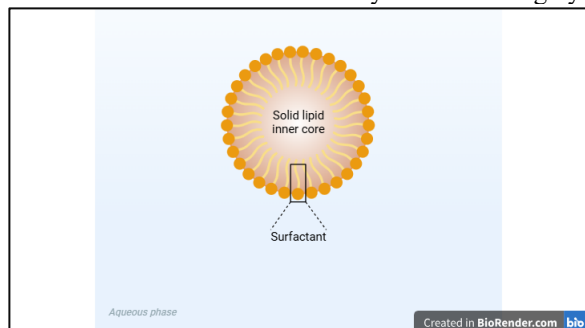


Figure 7: Solid lipid nanoparticles for drug delivery

Nanostructured lipid carriers

The second generation of lipid nanoparticles are called nanostructured lipid carriers, and they have a matrix made up of both liquid and solid lipids [11]. They are biodegradable and biocompatible, and they share structural similarities with skin lipids, especially SC lipids. Permeability and solubility are altered, bioavailability is increased, release is regulated, enzymatic degradation is reduced, transport across various biological barriers is facilitated, half-life is prolonged, and physicochemical and biological stability are enhanced [29].

The Griseofulvin-loaded nanostructured lipid carrier gel was created by N. Datt et al. to treat dermatophytosis. The optimized batch (f12) had a zeta potential of -44.12 mV, a drug release of 92.12%, an entrapment efficiency of 85.24%, and a particle size of 209 nm. They looked into histopathological tests against *T. rubrum* and *M. canis*, and found that this

formulation had a better effect than the commercial formulation and reduced oxidative stress by boosting antioxidant enzymes following treatment. They showed that G-NLCs function as a carrier to transport Griseofulvin to the dermatophytic patient in an efficient manner [30].

In order to treat fungal infections, Ameenuzzafar et al. created a nanostructured lipid carrier loaded with itraconazole that was made using the hot homogenization process. They evaluated the drug release ($77.23 \pm 3.33\%$), high entrapment efficiency ($86.36 \pm 0.83\%$), optimum batch particle size (147.31 ± 1.43 nm), and greater drug release ($88.43 \pm 2.54\%$ up to 24 h). According to their zone of inhibition results, ITZLNLCopt gel was roughly twice as potent as ITZL gel ($P < 0.05$). They showed that ITZNLC gel can be used as a substitute to treat fungal infections on the skin [31].

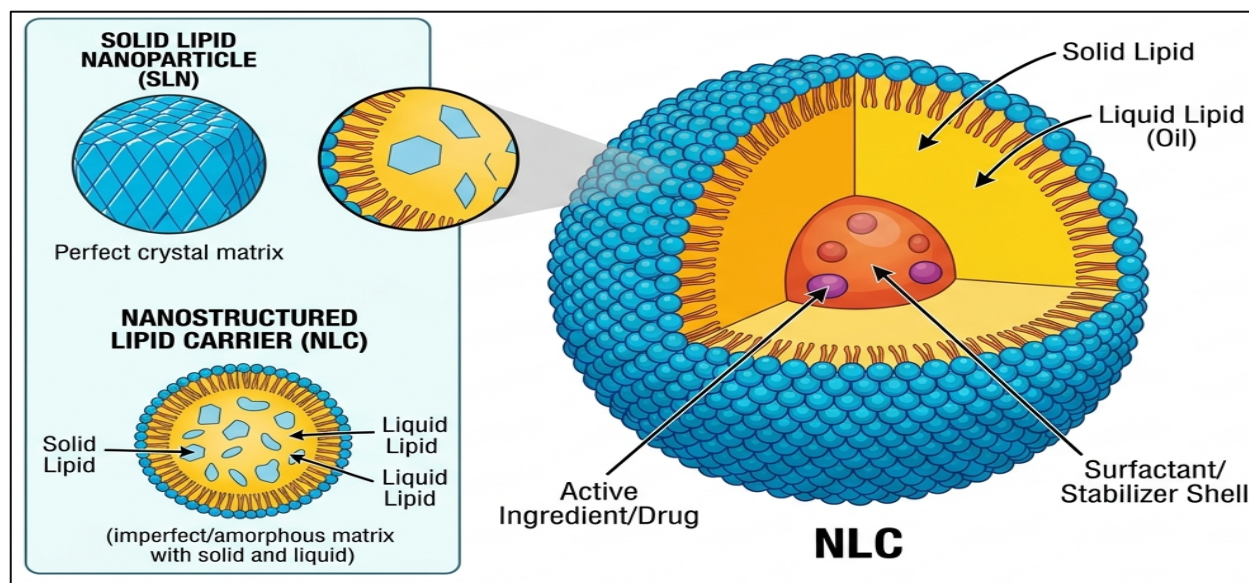


Figure 8: Nanostructured lipid carriers for drug delivery

4. Conclusion

Due to its high prevalence, rising recurrence rates, lengthy treatment regimens, and the development of antifungal resistance, dermatophytosis remains a major global healthcare concern. Conventional topical and systemic antifungal treatments are still the mainstay of treatment, but poor skin penetration, low bioavailability, limited drug retention, systemic side effects, and poor patient adherence often undermine their clinical efficacy. These drawbacks highlight the need for more effective and focused treatment approaches.

Drug delivery methods based on nanotechnology have surfaced as viable substitutes that could revolutionize the treatment of dermatophytosis. By improving drug solubility, stability, controlled release, targeted localization, and penetration across the stratum corneum, advanced nanocarriers such as liposomes, ethosomes, transfersomes, niosomes, solid lipid nanoparticles, nanostructured lipid carriers, phytosomes, dendrimers, nanogels, and polymeric nanoparticles offer significant benefits. When compared to traditional formulations, recent preclinical studies have consistently shown increased antifungal activity, extended drug residence duration, greater bioavailability, decreased dose frequency, and decreased systemic toxicity. Together, these characteristics lead to better treatment results and increased patient compliance.

There are still a number of obstacles to overcome before nano-formulations may be widely used in therapeutic settings, despite these promising developments. Successful translation from laboratory research to real world clinical practice is still hampered by problems with large-scale production, formulation stability, long-term safety, regulatory approval, cost-effectiveness, and the scarcity of reliable clinical studies. To prove the clinical superiority and financial viability of nanotechnology-based antifungal treatments, future research should focus on standardized formulation techniques, thorough pharmacokinetic and toxicological assessments, multicenter randomized clinical trials, and scalable manufacturing strategies.

All things considered, topical antifungal medication delivery by nanotechnology is a very promising field. Accelerating the development and clinical translation of safe, efficient, and patient-friendly nanotherapeutic systems will require ongoing interdisciplinary cooperation between pharmaceutical scientists, microbiologists, physicians, and regulatory bodies. In the age of precision and focused medicine, these developments have the potential to not only enhance the treatment of dermatophytosis but also to create new paradigms for the management of superficial fungal infections.

References

1. Kanbe T. Molecular approaches in the diagnosis of dermatophytosis. *Mycopathologia*. 2008 Nov;166:307-17.
2. AL-Khikani FH, Ayit AS. Major challenges in dermatophytosis treatment: current options and future visions. *Egyptian Journal of Dermatology and Venerology*. 2021 Jan 1;41(1):1-9.
3. Arenas R, del Rocío Reyes-Montes M, Duarte-Escalante E, Frías-De-León MG, Martínez-Herrera E. Dermatophytes and dermatophytosis. *Current Progress in Medical Mycology*. 2017:381-425.
4. Degreef H. Clinical forms of dermatophytosis (ringworm infection). *Mycopathologia*. 2008 Nov;166:257-65.
5. Hay RJ. Superficial mycoses. In: *Hunter's Tropical Medicine and Emerging Infectious Diseases* 2020 Jan 1 (pp. 648-652). Elsevier.
6. Bonifaz A, Archer-Dubon C, Saúl A. *Tinea imbricata* or Tokelau. *International journal of dermatology*. 2004 Jul;43(7):506-10.
7. Adams BB. *Tineacorporisgladiatorum*. *Journal of the American Academy of Dermatology*. 2002 Aug 1;47(2):286-90.
8. Romano C, Maritati E, Gianni C. *Tinea incognito* in Italy: a 15-year survey. *Mycoses*. 2006 Sep;49(5):383-7.
9. Bishnoi A, Mahajan R. *Tinea cruris*. *Diagnostics to Pathogenomics of sexually transmitted infections*. 2018 Nov 29;329-40.
10. Meena S, Bhadauria S. Clinical Manifestations of Dermatophytoses and its Treatment: A Review. *Asian Journal of Biology*. 2024 Jul 25;20(7):78-89.
11. Mousavi SA, Mokhtari A, Barani M, Izadi A, Amirbeigi A, Ajalli N, Amanizadeh A, Hadizadeh S. Advances of liposomal mediated nanocarriers for the treatment of dermatophyte infections. *Heliyon*. 2023 Aug 5.
12. Del Palacio A, Garau M, Gonzalez-Escalada A, Calvo MT. Trends in the treatment of dermatophytosis. *Biology of dermatophytes and other keratinophilic fungi*. Bilbao. 2000:148-58.
13. Rajagopalan M, Inamadar A, Mittal A, Miskeen AK, Srinivas CR, Sardana K, Godse K, Patel K, Rengasamy M, Rudramurthy S, Dogra S. Expert consensus on the management of dermatophytosis in India (ECTODERM India). *BMC dermatology*. 2018 Dec;18:1-1.
14. Sharma V, Kumawat TK, Sharma A, Seth R, Chandra S. Dermatophytes: Diagnosis of dermatophytosis and its treatment. *African*

- Journal of Microbiology Research. 2015 May 13;9(19):1286-93.
15. Aditya K G, Jennifer E R, Melody C, Elizabeth A C. Dermatophytosis: the management of fungal infections. *SKINmed: Dermatology for the Clinician*. 2005 Sep;4(5):305-10.
16. Alemayehu A, Minwuyelet G, Andualem G. Prevalence and etiologic agents of dermatophytosis among primary school children in Harari Regional State, Ethiopia. *Journal of Mycology*. 2016;2016(1):1489387.
17. Nene S, Shah S, Rangaraj N, Mehra NK, Singh PK, Srivastava S. Lipid based nanocarriers: A novel paradigm for topical antifungal therapy. *Journal of Drug Delivery Science and Technology*. 2021 Apr 1;62:102397.
18. Khurana A, Sardana K, Chowdhary A. Antifungal resistance in dermatophytes: Recent trends and therapeutic implications. *Fungal Genetics and Biology*. 2019 Nov 1;132:103255.
19. Mishra V, Singh M, Mishra Y, Charbe N, Nayak P, Sudhakar K, Aljabali AA, Shahcheraghi SH, Bakshi H, Serrano-Aroca A, Tambuwala MM. Nanoarchitectures in management of fungal diseases: An overview. *Applied Sciences*. 2021 Jul 31;11(15):7119.
20. Kumar L, Verma S, Bhardwaj A, Vaidya S, Vaidya B. Eradication of superficial fungal infections by conventional and novel approaches: a comprehensive review. *Artificial cells, nanomedicine, and biotechnology*. 2014 Feb 1;42(1):32-46.
21. Asadi P, Mehravaran A, Soltanloo N, Abastabar M, Akhtari J. Nanoliposome-loaded antifungal drugs for dermal administration: A review. *Current medical mycology*. 2021 Mar;7(1):71.
22. Nanda R, Kaur N, Narang JK. Formulation and Evaluation of Fluconazole Loaded Elastic Liposomes for the Treatment of Keratomycosis. *Current Trends in Biotechnology and Pharmacy*. 2021;15(6):58-61.
23. Mishra KK, Kaur CD, Gupta A. Development of itraconazole loaded ultra-deformable transethosomes containing oleic acid for effective treatment of dermatophytosis: Box-Behnken design, ex-vivo and in-vivo studies. *Journal of Drug Delivery Science and Technology*. 2022 Jan 1;67:102998.
24. Cheng Z, Kandekar U, Ma X, Bhabad V, Pandit A, Liu L, Luo J, Munot N, Chorage T, Patil A, Patil S. Optimizing fluconazole-embedded transfersomal gel for enhanced antifungal activity and compatibility studies. *Frontiers in Pharmacology*. 2024 Mar 28;15:1353791.
25. Osanloo M, Assadpour S, Mehravaran A, Abastabar M, Akhtari J. Niosome-loaded antifungal drugs as an effective nanocarrier system: A mini review. *Current medical mycology*. 2018 Dec;4(4):31.
26. Biju P, Shenoy MM, Tellis R, Bhat R, Das R, Prabhu A, Ahmed MG, Ghatge V. Novel Ketoconazole-Loaded Niosomal Gel with Carbamide for Enhanced Topical Delivery and Skin Hydration in Fungal Infections. *Journal of Pharmaceutical Innovation*. 2025 Apr;20(2):1-8.
27. Garg A, Sharma GS, Goyal AK, Ghosh G, Si SC, Rath G. Recent advances in topical carriers of anti-fungal agents. *Heliyon*. 2020 Aug 1;6(8).
28. Sreeharsha N, Prasanthi S, Rao GS, Gajula LR, Biradar N, Goudanavar P, Naveen NR, Shiroorkar PN, Meravanige G, Telsang M, Asif AH. Formulation optimization of chitosan surface coated solid lipid nanoparticles of griseofulvin: A Box-Behnken design and in vivo pharmacokinetic study. *European Journal of Pharmaceutical Sciences*. 2025 Jan 1;204:106951.
29. Nogueira NC, de Sá LL, de Carvalho AL. Nanostructured lipid carriers as a novel strategy for topical antifungal therapy. *AAPS PharmSciTech*. 2022 Jan;23:1-0.
30. Datt N, Poonuru RR, Yadav PK. Development and characterization of griseofulvin loaded nanostructured lipid carrier gel for treating dermatophytosis. *Food Hydrocolloids for Health*. 2022 Dec 1;2:100074.
31. Ameerduzzafar, Qumber M, Alruwaili NK, Bukhari SN, Alharbi KS, Imam SS, Afzal M, Alsuwayt B, Mujtaba A, Ali A. BBD-based development of itraconazole loaded nanostructured lipid carrier for topical delivery: in vitro evaluation and antimicrobial assessment. *Journal of pharmaceutical innovation*. 2021 Mar;16:85-98.