GSC Biological and Pharmaceutical Sciences

eISSN: 2581-3250 CODEN (USA): GBPSC2

Cross Ref DOI: 10.30574/gscbps

Journal homepage: https://gsconlinepress.com/journals/gscbps/

(REVIEW ARTICLE)

Check for updates

Nanotechnology-based approaches for acne treatment: A comprehensive review

Lalit D. Mahure *, Pooja R Hatwar, Ravindra L Bakal and Chetan C Turankar

Department of Pharmaceutics, Shri Swami Samarth Institute of Pharmacy, At Parsodi, Dhamangaon Rly. Dist.-Amravati (444709) Maharashtra, India.

GSC Biological and Pharmaceutical Sciences, 2025, 31(01), 156-162

Publication history: Received on 01 March 2025; revised on 13 April 2025; accepted on 15 April 2025

Article DOI: https://doi.org/10.30574/gscbps.2025.31.1.0150

Abstract

Acne vulgaris is a prevalent dermatological condition affecting millions worldwide, causing significant physical and emotional distress. Nanotechnology has emerged as a promising approach in the treatment and management of acne, offering improved drug delivery, enhanced efficacy, and reduced side effects. This review aims to provide a comprehensive overview of the application of nanotechnology in acne treatment, focusing on pathophysiology, clinical presentation, and management strategies. A detailed examination of various nanoparticle types utilized in anti-acne treatment, including liposomes, niosomes, solid lipid nanoparticles, and metal-based nanoparticles. The benefits and challenges of using nanotechnology in acne treatment are also explored, including concerns about toxicity and safety. Additionally, the regulatory framework surrounding nanotechnology in the European Union. This review highlights the potential of nanotechnology to revolutionize acne treatment and management, providing a promising avenue for future research and development.

Keywords: Acne vulgaris; Nanotechnology; Nanoparticles; Acne treatment

1. Introduction

Acne vulgaris is one of the most common dermatologic conditions globally [01]. The skin condition known as acne vulgaris affects the oil glands located at the base of hair follicles [02]. Development of acne may be individual or site-specific, with only a few follicles presenting the inflamed area yet at some stage in serious disease manifestations [03]. Acne is the most prevalent skin disease in the world, affecting 85% of adolescents and over 10% of adults [04]. Acne is associated with increased risks of stigmatization, bullying, depression, anxiety, poor self-esteem, and suicidal ideation [05].

Considered the most promising technology of the twenty-first century, nanotechnology is expected to have a significant positive impact on the cosmetics sector. The words "technology" and the Greek numeral "nano," which meaning dwarf, are combined to form the term "nanotechnology." Therefore, science and technology utilised to create or work with particles that range in size from 1 to 100 nm is known as nanotechnology [06]. Nanocarriers, including liposomes, niosomes, solid lipid nanoparticles, and micro-emulsions, provide protection for the encapsulated hydrophilic and lipophilic actives, target and control delivery while minimizing their toxicity toward other tissues, and allow higher skin penetration and time residence [07]. Acne is an inflammatory disease of pilosebaceous units in the skin of the face, neck, chest and upper back [08]. As nanomedicine technology continues to advance, nanotechnology has gradually emerged as a research hotspot in the field of drug delivery. Using nanotechnology, drugs may be synthesized into tiny particles to increase their water solubility [09]. Nanocarrier based transdermal drug delivery systems offer multiple advantages over conventional modes, such as enhanced physicochemical stability of drugs, increased skin permeation, improved biodistribution, effective targeted accumulation, and controlled drug delivery. Especially, nanocarriers can be applied

* Corresponding author: Lalit D. Mahure

in the hair follicle (HF)-targeted delivery to enhance the topical treatment outcomes of some appendage-related skin diseases, such as alopecia and acne [10].

In figure 1 highlights the difference between a normal skin and the skin with acne. In the skin with acne due to the excess production of male hormone androgen and oil producing glands in the face comedone occurs on the face. The closed comedone (whitehead) and ripen comedone (blackhead) are the primary two noninflammatory lesions in acne. These lesions may progress to inflammatory papules and pustules when the contents rupture. Larger, more painful lesions, such as cysts and nodules, may also develop. The application of novel delivery systems to the skin distributes the topical agent gradually, reduces the irritancy of some antiacne drugs, and shows good efficacy [11].

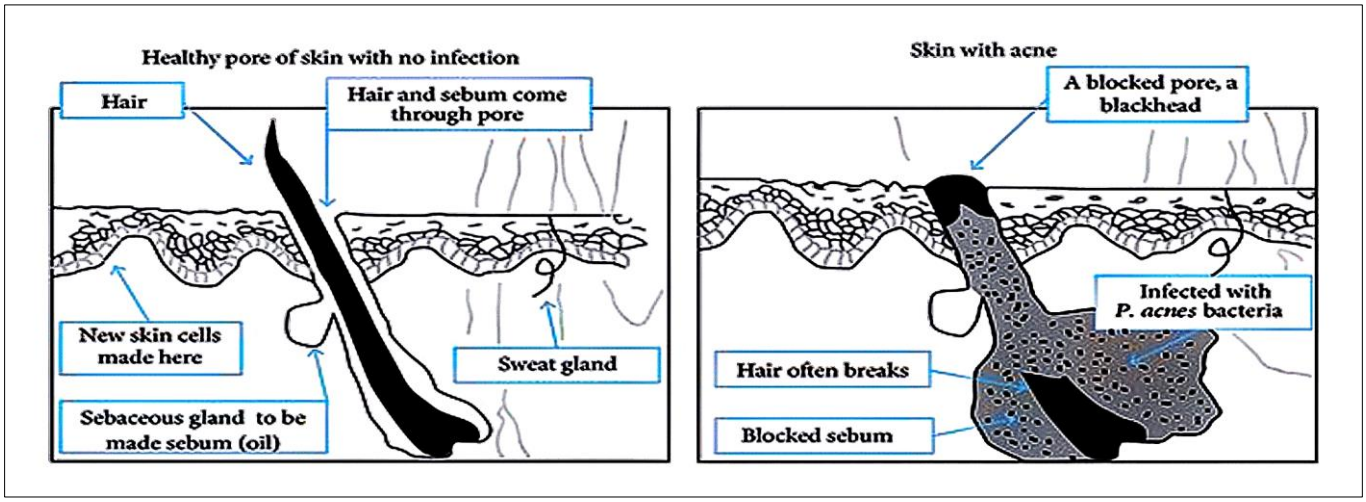

Figure 1 Difference between normal skin and skin with acne [11]

2. Causes of acne

Acne is mostly caused by a variety of reasons, including hormonal (Androgenic progestin), emotional, environmental (humidity, heat, etc.), and microorganisms.

One of the main reasons for acne forms is an increase in sebum production in the hair follicles [12].
Acne vulgaris is mainly caused by gram-positive, non-spore forming, micro-aerophilic and rod-like bacterium P. acnes [13].

Excessive colonization of these microbes promotes perifollicular inflammation. Therefore, increases in the development of Cutibacterium acne and inflammatory processes are additional causes of acne development [14].

One of many causes of acne vulgaris is the proliferation of Propionibacterium acnes (P. acnes), a normal anaerobic flora found in sebaceous glands [15].

3. Types of nanoparticles for Acne treatment

There have been several nanotechnology-based formulations that have been proved to be efficient for acne treatment and care. In this section, describe lipid nanoparticles polymeric-based nanosystems, metal-based nanoparticles and additional nanosystems (Figure 2) [16].

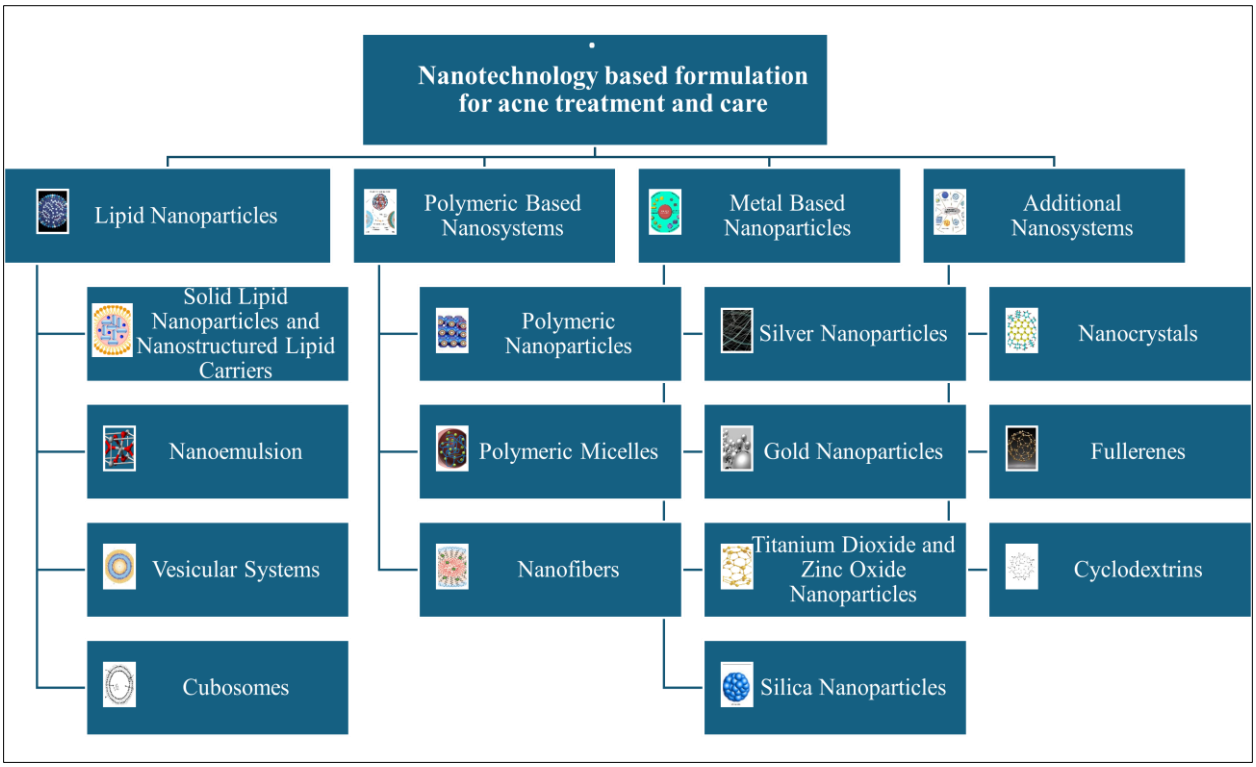

Figure 2 Schematic compilation of nanotechnology-based formulations for acne treatment and care [16]

3.1. Liposomes

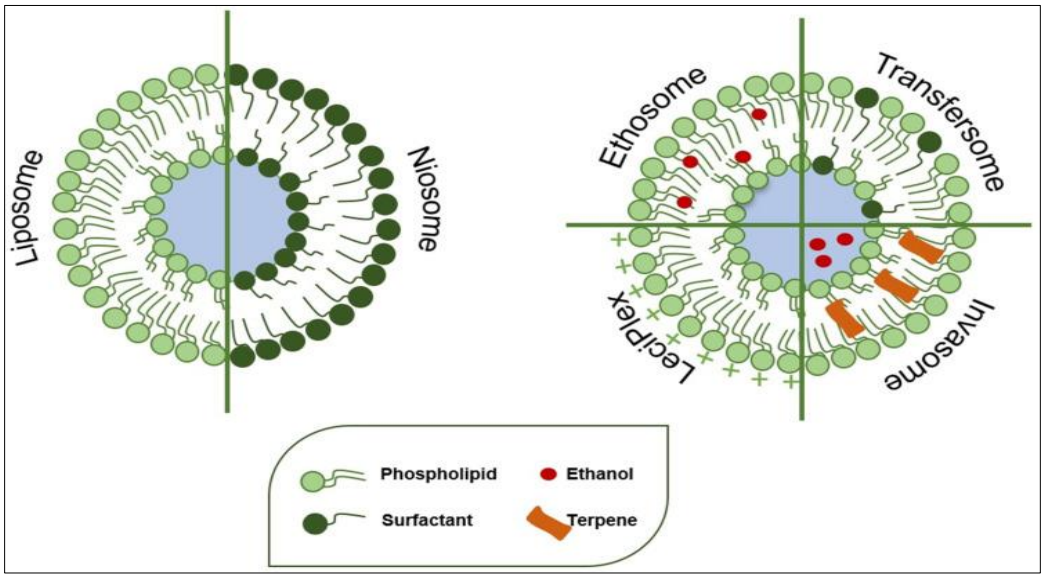

Figure 3 Schematic representation of liposomes and liposomal-like vesicles [18]

Liposomes can promote drug deposition in the skin at the site of action, decrease systemic absorption, and minimize adverse effects, all of which contribute to a localized effect of anti-acne medications. Additionally, they can boost the drug's systemic absorption by targeting it to skin appendages. They can lessen the negative effects and increase the therapeutic efficacy of medications [11]. Liposomes have found significant applications in dermal and transdermal drug delivery, including their targeted delivery to skin appendages. In the context of dermal drug delivery, liposomes are employed to enhance drug penetration into the skin ensuring localized therapeutic levels while minimizing percutaneous absorption [17]. Conventional liposomes are one of the most famous and extensively studied lipid vesicles, which are typically composed of phospholipids, cholesterol, and aqueous medium (water or buffer solution with varying pH). These vesicles are formed when naturally or synthetically occurring biodegradable lipids come into

contact with the aqueous medium, wherein the hydrophilic head group of the lipid surrounds the aqueous core while the hydrophobic tail group is exposed to the external medium. Due to this unique structural property, water-soluble drugs can be loaded in the aqueous core while the water-insoluble drugs can be loaded in the lipid bilayer [18].

3.2. Niosomes

Niosomes are vesicular drug delivery systems that have a long shelf life, a sustained drug release profile, and improved penetration of the stratum corneum or intradermal passageways [19]. One of the most promising drug delivery methods for the treatment of skin conditions is niosomes. When given topically, niosomes can decrease systemic absorption of the medicine while increasing its residence time in the stratum corneum and epidermis [11]. Microsponge delivery systems of (Benzoyl peroxide) BPO, niosomal gel formulations and solid lipid nanoparticles have been reported in the article [20] Niosomes are nanosized colloidal vesicular structures formed by the self-assembly of non-ionic surfactants in an aqueous environment resulting in a bilayer configuration [21].

3.3. Solid Lipid Nanoparticles (SLNs)

In the 1990s, SLNs were introduced as a viable alternative to traditional colloidal carriers, including liposomes and polymeric nanoparticles, to account for the potential for industrial-scale production [22]. In 2012, a study showed the improvement of the properties of SLNs, as a carrier, by adding chitosan to SLNs loaded with (Trusted Research Environment) TRE. It was found that low TRE concentrations in TRE loaded SLNs with chitosan inhibited acne-causing bacteria, such as C. acnes and S. aureus, with a MIC of 40 μg/ml and 300 μg/ml, respectively [16]. According to a published study, when compared to free medications for the treatment of psoriasis, SLNs could considerably improve the quantity and depth of cyclosporine A and calcipotriol skin penetration [23].The liposome micelle structure is released by Solid Lipid Nanoparticles (SLN) and Nanostructured Lipid Carriers (NLC), which are safe for delivering and releasing active ingredients to the skin and stable in both lipophilic and hydrophilic environments [24].

4. Example of nanotechnology based on anti-acne product

4.1. Benzoyl peroxide (BPO)

A topical non-antibiotic disinfectant, is used to treat mild to moderate acne because of its antibacterial and disinfecting properties [12]. Benzoyl peroxide is a crucial treatment for mild to moderate acne. While it can be used alone for 6–8 weeks, topical antibiotics are frequently used in conjunction with it to lessen P. acnes species resistance and boost treatment effectiveness [25].

4.2. Salicylic acid

A beta hydroxyl molecule with bacteriostatic, fungistatic, and anti-inflammatory qualities is salicylic acid. When applied topically, it keeps pores clear and exfoliates the skin to lessen acne. Although salicylic acid is safe to use, it can occasionally irritate, itchy, and dry out the skin [12]. Salicylic acid is an over-the-counter topical comedolytic medication that comes in concentrations between 0.5% and 2% [05].

5. Therapeutic Agent for Acne Treatment: Antibacterial, Anti-inflammatory, and Comedolytic Properties

5.1. Antibacterial Activity

The health and medical fields have conducted the most extensive research and development of technology that utilises the antibacterial properties of nanoparticles [26]. Zinc lowers inflammation and has antibacterial qualities against candida acnes [27]. Benzoyl peroxide is used to treat mild to moderate acne since it is an antibacterial and topical non-antibiotic disinfectant [12]. Furthermore, tretinoin-containing SLNs with and without chitosan were made to evaluate their antibacterial activity against microorganisms linked to acne and cytotoxicity in keratinocytes [17].

5.2. Anti-inflammatory activity

An active version of vitamin B3, nicotinamide is being studied more and more in the field of dermatology. This nutraceutical is a great option for treating acne because it has anti-inflammatory qualities and has been demonstrated to lower sebum production [19]. Willow bark extract contains salicin, an alcoholic β-glucoside with anti-inflammatory and high comedolytic properties that are used to treat skin conditions including acne [22].

5.3. Comidolytic activity

Benzoyl peroxide (BPO) is an anti-bacterial topical medication that kills P. acnes by the generation of free oxygen radicals and is also weakly keratolytic and comedolytic action [28]. Physical excision of microcysts, macrocomedones or closed comedones will boost the therapeutic efficacy of topically applied comedolytic drugs [25].

6. Challenges and future direction

6.1. Concerns about toxicity and safety

The short and long-term health impacts of nanoparticles on organisms and the environment are little understood, despite their immense benefits. Because of the nanomaterials' documented toxicity and potential risks, safety concerns have been raised [06]. Clarifying the long-term health advantages and possible negative consequences should be the main goal of future research. The physicochemical, anti-inflammatory, immunomodulatory, antioxidant, and DNA repair capabilities of polyphenols primarily determine their effects on the skin and can be used to prevent a range of skin conditions [29].

The future challenges of nanotechnology-based preparations for the treatment as well as care of acne are as follows:

- The absence of systemic absorption
- The prevention of nano contamination
- Ensure human health and safety
- Stricter regulatory framework [16]

7. Conclusion

Nanotechnology has shown significant promise in the treatment and management of acne vulgaris, offering improved drug delivery, enhanced efficacy, and reduced side effects. The various types of nanoparticles used in anti-acne treatment, including liposomes, niosomes, solid lipid nanoparticles, and metal-based nanoparticles, have demonstrated potential in targeting the underlying causes of acne. However, concerns about toxicity and safety must be addressed through further research and development. The regulatory framework surrounding nanotechnology in the European Union provides a foundation for the safe and effective use of nanotechnology in treatment with acne. As research continues to advance, nanotechnology is likely to play an increasingly important role in the management of acne vulgaris, providing new and innovative treatment options for millions of people worldwide. Ultimately, the integration of nanotechnology into acne treatment has the potential to revolutionize the field, improving patient outcomes and quality of life.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] Baldwin H, Tan J. Effects of Diet on Acne and Its Response to Treatment. Am J Clin Dermatol. 2021 Jan;22(1):55-65. doi: 10.1007/s40257-020-00542-y. Erratum in: Am J Clin Dermatol. 2021 Jan;22(1):67. doi: 10.1007/s40257-020-00576-2. PMID: 32748305; PMCID: PMC7847434.

[2] Tayyaba Rana, Muhammad Zaman, Mahtab Ahmed Khan, Abdul Qayyum Khan, Muhammad Jamshaid, Nehal Ahmed Talaat Nouh, Fatma M. El-Demerdash, Mohamed Kamel, Mohamed M. Abdel-Daim, Ghadeer M. Albadrani, Sumiyya Javaid and Zainab Naeem. Antiacne Gel Containing Aloe vera and Clindamycin Phosphate: Design, Characterization, and Optimization Using Response Surface Methodology. International Journal of Polymer Science. 2024:1-17. https://doi.org/10.1155/2024/3353141

[3] Bharti S, Vadlamudi HC. A strategic review on the involvement of receptors, transcription factors and hormones in acne pathogenesis. J Recept Signal Transduct Res. 2021;41(2):105-116. doi: 10.1080/10799893.2020.1805626. Epub 2020. PMID: 32787477.

[4] Taylor EJ, Yu Y, Champer J, Kim J. Resveratrol Demonstrates Antimicrobial Effects Against Propionibacterium acnes In Vitro. Dermatol Ther (Heidelb). 2014 Dec;4(2):249-57. doi: 10.1007/s13555-014-0063-0. Epub 2014. PMID: 25228291; PMCID: PMC4257953.

[5] Reynolds RV, Yeung H, Cheng CE, Cook-Bolden F, Desai SR, Druby KM, Freeman EE, Keri JE, Stein Gold LF, Tan JKL, Tollefson MM, Weiss JS, Wu PA, Zaenglein AL, Han JM, Barbieri JS. Guidelines of care for the management of acne vulgaris. J Am Acad Dermatol. 2024 ;90(5):1006.e1-1006.e30. doi: 10.1016/j.jaad. Epub 2024. PMID: 38300170.

[6] Kaul S, Gulati N, Verma D, Mukherjee S, Nagaich U. Role of Nanotechnology in Cosmeceuticals: A Review of Recent Advances. J Pharm (Cairo). 2018:3420204. doi: 10.1155/2018/3420204. PMID: 29785318; PMCID: PMC5892223.

[7] Ivanova K, Ramon E, Ivanova A, Sanchez-Gomez S, Tzanov T. Bio-Based Nano-Enabled Cosmetic Formulations for the Treatment of Cutibacterium acnes-Associated Skin Infections. Antioxidants (Basel). 2023 ;12(2):432. doi: 10.3390/antiox12020432. PMID: 36829991; PMCID: PMC9952472.s

[8] Raza K, Singh B, Singal P, Wadhwa S, Katare OP. Systematically optimized biocompatible isotretinoin-loaded solid lipid nanoparticles (SLNs) for topical treatment of acne. Colloids Surf B Biointerfaces. 2013;105:67-74. doi: 10.1016/j.colsurfb.2012.12.043. Epub 2013. PMID: 23357735.

[9] Lei Y, Jiang W, Peng C, Wu D, Wu J, Xu Y, Yan H, Xia X. Advances in polymeric nano-delivery systems targeting hair follicles for the treatment of acne. Drug Delivery 2024 ;31(1):2372269. doi: 10.1080/10717544.2024.2372269. Epub 2024. PMID: 38956885; PMCID: PMC11225637.

[10] Qu F, Geng R, Liu Y, Zhu J. Advanced nanocarrier- and microneedle-based transdermal drug delivery strategies for skin diseases treatment. Theranostics. 2022;12(7):3372-3406. doi: 10.7150/thno.69999. PMID: 35547773; PMCID: PMC9065205.

[11] Vyas A, Kumar Sonker A, Gidwani B. Carrier-based drug delivery system for treatment of acne. ScientificWorldJournal. 2014; 2014:276260. doi: 10.1155/2014/276260. PMID: 24688376; PMCID: PMC3934386.

[12] Vasam M, Korutla S, Bohara RA. Acne vulgaris: A review of the pathophysiology, treatment, and recent nanotechnology based advances. Biochem Biophys Rep. 2023; 36:101578. doi: 10.1016/j.bbrep.2023.101578. PMID: 38076662; PMCID: PMC10709101.

[13] Garg T. Current nanotechnological approaches for an effective delivery of bio-active drug molecules in the treatment of acne. Artif Cells Nanomed Biotechnol. 2016; 44(1):98-105. doi: 10.3109/21691401.2014.916715. Epub 2014. PMID: 24844191.

[14] Koch W, Zagórska J, Michalak-Tomczyk M, Karav S, Wawruszak A. Plant Phenolics in the Prevention and Therapy of Acne: A Comprehensive Review. Molecules. 2024; 29(17):4234. doi: 10.3390/molecules29174234. PMID: 39275081; PMCID: PMC11397085.

[15] Pan-In P, Wongsomboon A, Kokpol C, Chaichanawongsaroj N, Wanichwecharungruang S. Depositing α-mangostin nanoparticles to sebaceous gland area for acne treatment. J Pharmacol Sci. 2015 ;129(4):226-32. doi: 10.1016/j.jphs.2015.11.005. Epub 2015 Nov 19. PMID: 26701606.

[16] Paiva-Santos AC, Mascarenhas-Melo F, Coimbra SC, Pawar KD, Peixoto D, Chá-Chá R, Araujo AR, Cabral C, Pinto S, Veiga F. Nanotechnology based formulations toward the improved topical delivery of anti-acne active ingredients. Expert Opin Drug Delivery. 2021; 18(10):1435-1454. doi: 10.1080/17425247.2021.1951218. Epub 2021. PMID: 34214003.

[17] Dragicevic N, Maibach HI. Liposomes and Other Nanocarriers for the Treatment of Acne Vulgaris: Improved Therapeutic Efficacy and Skin Tolerability. Pharmaceutics. 2024; 16(3):309. doi: 10.3390/pharmaceutics16030309. PMID: 38543203; PMCID: PMC10974767.

[18] Mancuso A, Cristiano MC, Fresta M, Paolino D. The Challenge of Nanovesicles for Selective Topical Delivery for Acne Treatment: Enhancing Absorption Whilst Avoiding Toxicity. Int J Nanomedicine. 2020;15:9197-9210. doi: 10.2147/IJN.S237508. PMID: 33239876; PMCID: PMC7682599.

[19] Chakraborty N, Narayanan V, Gautam HK. Nano-Therapeutics to Treat Acne Vulgaris. Indian J Microbiol. 2022; 62(2):167-174. doi: 10.1007/s12088-022-01001-4. Epub 2022. PMID: 35462720; PMCID: PMC8980181.

[20] Kahraman E, Özhan G, Özsoy Y, Güngör S. Polymeric micellar nanocarriers of benzoyl peroxide as potential follicular targeting approach for acne treatment. Colloids Surf B Biointerfaces. 2016;146:692-9. doi: 10.1016/j.colsurfb.2016. Epub 2016. PMID: 27434156.

[21] Alam Zeb,Sadia Tabassam Arif, Maimoona Malik, Fawad Ali Shah, Fakhar Ud Din, Omer Salman Qureshi, Eun-Sun Lee, Gwan-Yeong Lee, Jin-Ki Kim, Potential of nanoparticulate carriers for improved drug delivery via skin, Journal of Pharmaceutical Investigation (2019) 49:485–517.

[22] Chutoprapat R, Kopongpanich P, Chan LW. A Mini-Review on Solid Lipid Nanoparticles and Nanostructured Lipid Carriers: Topical Delivery of Phytochemicals for the Treatment of Acne Vulgaris. Molecules. 2022; 27(11):3460. doi: 10.3390/molecules27113460. PMID: 35684396; PMCID: PMC9182464.

[23] Jain S, Patel N, Shah MK, Khatri P, Vora N. Recent Advances in Lipid-Based Vesicles and Particulate Carriers for Topical and Transdermal Application. J Pharm Sci. 2017; 106(2):423-445. doi: 10.1016/j.xphs.2016.10.001. Epub 2016. PMID: 27865609.

[24] Tiwari R, Jain R, Agrawal O.P, Shukla AK, Metallic-nano-particles: encapsulated-form of bioactive compounds, types of carriers, advantages, toxicity, future prospects and their role in the treatment of acne disease. Journal of Advanced Scientific Research. 2020; 11(4): 01-07.

[25] Fox L, Csongradi C, Aucamp M, du Plessis J, Gerber M. Treatment Modalities for Acne. Molecules. 2016; 21(8):1063. doi: 10.3390/molecules21081063. PMID: 27529209; PMCID: PMC6273829.

[26] Falke PB, Shelke PG, Hatwar PR, Bakal RL and Kohale NB. A comprehensive review on Nanoparticle: Characterization, classification, synthesis method, silver nanoparticles and its applications. GSC Biological and Pharmaceutical Sciences. 2024; 28(01): 171–184

[27] Kim HJ, Kim YH. Exploring Acne Treatments: From Pathophysiological Mechanisms to Emerging Therapies. Int J Mol Sci. 2024;25(10):5302. doi: 10.3390/ijms25105302. PMID: 38791344; PMCID: PMC11121268.

[28] Melnik BC. p53: key conductor of all anti-acne therapies. J Transl Med. 2017; 15(1):195. doi: 10.1186/s12967-017-1297-2. PMID: 28927457; PMCID: PMC5606086.

[29] Farhan M. The Promising Role of Polyphenols in Skin Disorders. Molecules. 2024; 29(4):865. doi: 10.3390/molecules29040865. PMID: 38398617; PMCID: PMC10893284