Understanding The Use of Transdermal Patches in Psoriasis: A Literature Review From 2020-2025

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Abstract— **Psoriasis is a chronic, immune-mediated inflammatory skin disorder that requires long-term management and poses significant challenges due to impaired skin barrier function and systemic side effects associated with conventional therapies. Transdermal drug delivery systems, particularly transdermal patches, have emerged as a promising alternative to oral and injectable treatments by enabling localized, controlled, and minimally invasive drug administration. This review highlights recent advancements in transdermal patch technologies for psoriasis therapy, with a specific focus on microneedle-assisted systems, nanocarrier-integrated patches, and multifunctional wearable platforms developed between 2020 and 2025. Advanced transdermal patches incorporating nanocarriers such as liposomes, ethosomes, cubosomes, mesoporous silica nanoparticles, and nanosuspensions have demonstrated enhanced skin penetration, sustained drug release, and improved therapeutic efficacy. Microneedle-based patches further overcome the thickened psoriatic stratum corneum by creating transient microchannels, enabling efficient delivery of corticosteroids, immunosuppressants, small-molecule inhibitors, peptides, proteins, and even gene-editing agents. Recent studies also emphasize dual-drug and stimuli-responsive systems that combine rapid anti-inflammatory action with long-term immunomodulation, resulting in superior disease control and reduced systemic toxicity. Preclinical and early clinical investigations consistently report significant reductions in psoriatic severity indices, inflammatory cytokines, and epidermal hyperplasia, alongside improved patient compliance and safety profiles. Despite remaining challenges related to large-scale manufacturing, regulatory approval, and long-term safety assessment, transdermal patch-based drug delivery systems represent a transformative approach for personalized and targeted psoriasis therapy.**

Keywords— **Psoriasis; Transdermal patches; Microneedles; Nanocarriers; Controlled drug delivery**

I. INTRODUCTION

Transdermal patches are non-invasive drug delivery systems designed to administer therapeutic agents across the skin into systemic circulation or targeted skin layers at a controlled rate. They offer several advantages over conventional oral and injectable dosage forms, including avoidance of first-pass hepatic metabolism, improved patient compliance, sustained drug release, and reduced dosing frequency. A typical transdermal patch consists of a drug reservoir or matrix, polymeric backing layer, pressure-sensitive adhesive, and a release-controlling membrane. Recent advances have expanded traditional patch designs to include nanocarrier-based systems, hydrogel patches, and microneedle-assisted platforms, enabling the delivery of both hydrophilic and lipophilic drugs with improved permeation and therapeutic efficiency [1,2].

Psoriasis is a chronic, immune-mediated inflammatory skin disorder characterized by excessive keratinocyte proliferation, epidermal thickening, and infiltration of inflammatory cytokines. Conventional topical therapies often suffer from poor penetration due to the thickened stratum corneum, while systemic therapies are associated with significant adverse effects and long-term safety concerns. Transdermal patch systems have therefore gained increasing attention for psoriasis management, as they allow localized and sustained drug delivery directly to diseased skin while minimizing systemic exposure [3]. The controlled release capability of patches helps maintain consistent drug levels in psoriatic lesions, reducing flare-ups and improving therapeutic outcomes.

Recent review studies emphasize the role of advanced transdermal strategies such as nanocarrier-loaded patches (liposomes, ethosomes, transfersomes, solid lipid nanoparticles) and dissolving microneedle patches in overcoming the skin barrier associated with psoriasis [2,4]. Microneedle-based transdermal patches create temporary microchannels in the skin, enhancing penetration of corticosteroids, immunosuppressants, small molecules, and even biologics without causing pain or bleeding. These systems have demonstrated superior drug deposition in the epidermis and dermis, improved anti-inflammatory response, and reduced systemic toxicity in preclinical psoriasis models.

Overall, transdermal patch technology represents a promising and patient-friendly approach for psoriasis therapy. Current research trends (2020–2025) highlight the development of multifunctional and combination drug patches, responsive release systems, and minimally invasive microneedle platforms aimed at long-term disease control and improved quality of life. Although challenges such as large-scale manufacturing, regulatory approval, and long-term safety evaluation remain, transdermal patches are emerging as a viable alternative or adjunct to existing psoriasis treatment modalities [1,5].

II. LITERATURE ANALYSIS

MLi et al. (2025) developed a soluble double-layer microneedle patch containing Methylprednisolone (MP) and Upadacitinib (UPA) loaded in mesoporous silica (SBA-15) nanocomposites. The patch was designed as an immediate-release–controlled-release system to achieve rapid anti-inflammatory effects and sustained immunosuppression. The outer layer is a mechanically robust gelatin–polyvinyl alcohol (Gel–PVA) hydrogel loaded with MP, while the inner layer is a light-curable methacrylated hyaluronic acid (MeHA) network encapsulating UPA-loaded mesoporous silica (UPA/SBA-15). This microneedle platform provides pain-free, precise, and low-toxicity transdermal delivery of glucocorticoids and JAK1 inhibitors, combining mechanical penetration with mesoporous silica–mediated sustained release, and showed significant anti-psoriatic effects in a preclinical model, demonstrating translational potential for personalized psoriasis therapy [6].

Mengting Zhuo et al developed a dissolvable microneedle patch synergistic herbal shikonin-loaded tetrahedral framework nucleic acids for psoriasis therapy"Despite advances in microneedle-assisted delivery, conventional systems often exhibit suboptimal pharmacokinetics and limited therapeutic versatility. In this work, we developed a dissolvable microneedle (MN) patch composed of selenium-functionalized hyaluronic acid (SeHA) integrated with shikonin-loaded tetrahedral framework nucleic acids (SFN) to achieve sustained drug release and modulate the ROS-rich psoriatic microenvironment.In vitro, SFN enhanced shikonin uptake, inhibited keratinocyte hyperproliferation, and promoted apoptosis, while SeHA effectively scavenged ROS and reduced oxidative stress. In vivo, the MN system significantly improved psoriatic symptoms, decreasing epidermal thickening and systemic inflammation, and demonstrated excellent biocompatibility [7].

Elham Momtaz et al developed a Piezoelectric-Driven Microneedle.drug use of Methotrexate , Methotrexate (MTX) is one of the mainstays in the treatment of psoriasis, but oral MTX can cause gastrointestinal side effects, and subcutaneous injections are often painful and may reduce patient compliance. To overcome these limitations, explored a minimally invasive transdermal delivery strategy using a piezoelectric-driven microneedle array (PDMA), which can efficiently penetrate the thickened psoriatic epidermis and enable controlled MTX delivery.PDMA produced a significant enhancement in MTX permeation, achieving a 9-fold increase in delivery depth compared with untreated skin. In vivo, PDMA-mediated MTX delivery markedly improved therapeutic outcomes, outperforming oral MTX administration while using only 50% of the standard oral dose [8].

S L Jyothi 2025 Aug et al developed a Cubosome-dissolving microneedle system enhances the anti-psoriatic efficacy of a synergistic combination of methotrexate and cyclosporine. Conventional systemic therapies such as methotrexate and cyclosporine are effective but often cause significant systemic toxicity and require high doses. To address these limitations, a targeted and minimally invasive transdermal system was developed using cubosome-embedded dissolving microneedles co-loaded with MTX and CYS [9]."

Laxiangge Li jul2025 et al developed a Driven Microneedle Array Delivery of Methotrexate for Enhanced Psoriasis Treatment Methotrexate (MTX) is a mainstay in the treatment of psoriasis and psoriatic arthritis, but oral MTX can cause gastrointestinal side effects, and subcutaneous injections are often painful, which may reduce patient compliance. To overcome these limitations, we explored a minimally invasive transdermal delivery approach using a piezoelectric-driven microneedle array (PDMA), capable of efficiently penetrating the thickened epidermis and enabling controlled MTX delivery. PDMA significantly enhanced MTX permeation, achieving a 9-fold increase in delivery depth compared with untreated skin [10].

Tejpal Yadav may 2025 et al developed a novel pemetrexed disodium-loaded transdermal patches in an imiquimod-induced mouse model. Current therapies, such as corticosteroids and biologics, have limitations including side effects and poor skin penetration. We evaluated pemetrexed disodium formulated in a transdermal patch for psoriasis in a mouse model.Mice treated with the patches showed dose-dependent reductions in PASI scores and inflammatory cytokines[11].

Hyun Jeong Ju 2025 Apr et al developed a Acid-Based Dissolving Microneedle Patches to Treat Psoriatic Plaques , to the use of Hyaluronic Acid. Topical medicines are commonly used for localized psoriasis, but their entry through the thick, scaly skin is slow and often not enough to produce strong results. In this work, we examined whether dissolving microneedle (DMN) patches could boost skin penetration and improve the effectiveness of betamethasone + calcipotriol ointment. Clinically, the group receiving the DMN patch along with the ointment showed the most notable drop in mPASI scores, outperforming both the ointment-alone group and the group using patches without needles. Laboratory (in vitro and ex vivo) evaluations confirmed proper micro-channel creation, quick needle dissolution, and nearly a 2-fold rise in drug permeation [12].

Akshad Balde may 25 et al developed a microneedle patch as a delivery system for proteins/peptides Transdermal delivery is being explored as an alternative to oral and IV routes, which often cause side effects or degrade sensitive drugs. Microneedle patches offer a minimally invasive way to deliver peptides and proteins directly into the skin for conditions like psoriasis, dermatitis, and arthritis. This review summarizes microneedle fabrication methods, recent advances in peptide/protein-loaded microneedles, and future challenges in developing effective patches[13].

Zohreh Bazargani April 2025 et al developed a comparative analysis of clobetasol-loaded microneedle patches versus clobetasol propionate ointment in experimental induced-psoriasis model. Dissolvable microneedles (MNs) offer a promising approach for psoriasis treatment. A polyvinylpyrrolidone MN patch was developed to deliver Clobetasol 17-Propionate, and its physical properties, including morphology, solubility, strength, and skin penetration, were evaluated.”The MN patch showed rapid drug release within 10 minutes, dissolved in skin in ~20 minutes, and penetrated up to 200 µm in mice. In an imiquimod-induced psoriasis model, CP-loaded MNs effectively reduced disease severity, demonstrating fast and efficient drug[14].

Jun Li nov 2024 et al developed a Microneedle patches incorporating zinc-doped mesoporous silica nanoparticles loaded with betamethasone dipropionate for psoriasis treatment Psoriasis treatment is often limited by the drawbacks of topical glucocorticoids. To address this, a microneedle system incorporating zinc-doped mesoporous silica nanoparticles (Zn-MSN) was developed for the sustained delivery of betamethasone dipropionate (BD). The BD@Zn-MSN-MN system enhanced anti-inflammatory activity by promoting M2 macrophage polarization and alleviated itching psoriatic mice by reducing TRPV1 neuron excitability and CGRP release, presenting a promising strategy for transdermal psoriasis therapy[15].

Xiaodie Li oct.2024 et al developed a Biomineralized in-place catalytic nanoreactor embedded microneedle patch for controlled immunomodulator delivery against psoriasis.“The endogenous immunomodulator adenosine (ADO) has limited therapeutic effect due to poor stability and low accumulation in psoriatic skin. To overcome this, a biomineralized in situ catalytic nanoreactor was developed by encapsulating AMP within a porous framework and incorporating it into dissolving microneedles for precise delivery to psoriasis lesions. After penetrating the skin, the nanoreactors gradually released AMP and catalytically generated ADO, modulating the inflammatory environment by reducing keratinocyte hyperproliferation, lowering pro-inflammatory cytokine levels, and regulating immune cell infiltration. This strategy demonstrated promising efficacy in a psoriasis-like mouse model[16].

Zi Yi Wang dec.24 et al developed a Self-locking microneedles deliver antiproliferative and immunomodulatory drugs to treat. psoriasis.Deucravacitinib (Deu), a TYK2 inhibitor, is effective against psoriasis but can cause systemic side effects and has limited efficacy on thickened lesions. To address this, a self-locking microneedle patch was designed with a PVA inner ring loaded with Deu, allowing efficient skin penetration and rapid dissolution, specifically targeting the IL-23/IL-17 pathway. The outer layer, composed of methacrylated hyaluronic acid with calcipotriol (Cal), ensures localized retention and sustained anti-proliferative activity. The Deu@Cal MN exhibited strong adhesion, controlled and targeted drug release, reduced skin inflammation and keratinocyte proliferation, and inhibited Th17 cell differentiation, representing a promising therapeutic approach for psoriasis[17].

Tong Wu sep.2024 Mengting Zhuo et al developed a Microneedle patches loaded with RONS from plasma-activated ice enable transdermal treatment of psoriasis.Cold atmospheric plasma (CAP) is a noninvasive treatment for psoriasis, but its clinical application is limited by insufficient generation and delivery of reactive oxygen and nitrogen species (RONS). To overcome this, air-discharge plasma-activated ice microneedle (PA-IMN) patches were developed to deliver RONS locally through the skin, providing an alternative to direct CAP therapy.The PA-IMNs suppressed keratinocyte hyperproliferation via ROS-mediated apoptosis and markedly reduced inflammation in an imiquimod-induced psoriasis mouse model[18].

Mengting Zhuo oct.2025 et al developed a A selenium-functionalized hyaluronic acid dissolvable microneedle patch delivering shikonin-loaded tetrahedral framework nucleic acids for psoriasis therapy.Conventional microneedle-assisted delivery systems often face challenges with limited pharmacokinetics and therapeutic versatility. To address this, a dissolvable microneedle (MN) patch was developed using selenium-functionalized hyaluronic acid (SeHA) combined with shikonin-loaded tetrahedral framework nucleic acids (SFN), enabling sustained drug release and modulation of the ROS-rich psoriatic microenvironment.In vitro, SFN enhanced shikonin uptake, suppressed keratinocyte proliferation, and induced apoptosis, while SeHA effectively scavenged ROS. In vivo, the MN patch improved psoriatic lesions, decreased epidermal thickening and systemic inflammation, and demonstrated excellent biocompatibility, highlighting its potential as a targeted therapy for psoriasis[19].

Die Li nov.2025 et al developed a double-layer microneedle patch delivering Methylprednisolone and Upadacitinib-loaded mesoporous silica nanocomposites for psoriasis treatment.Psoriasis is driven by IL-23/IL-17 signaling, and conventional oral or topical therapies often struggle to balance acute flare control with long-term management. To address this, a dual-layer soluble microneedle (MN) patch was developed, combining methylprednisolone (MP) for rapid anti-inflammatory action and upadacitinib (UPA) for sustained immunosuppression. The outer Gel-PVA layer released approximately 70% of MP within 2 hours, while UPA from the inner MeHA/SBA-15 layer was gradually released over 48 hours, significantly lowering IL-17A, IL-1β, IL-6, and TNF-α levels. In mice, this patch achieved ~90% PASI reduction, normalized epidermal thickness, reduced inflammatory markers more effectively than tacrolimus, and showed no systemic toxicity, demonstrating precise and low-toxicity transdermal delivery[20].

Miquel Martínez-Navarrete dec.2024 et al developed a Dissolving microneedles loaded with Cyclosporin A for dermatitis therapy. evaluated for development, characterization, and efficacy in a delayed-type hypersensitivity in vivo model.Topical delivery is preferred for chronic inflammatory skin disorders to minimize systemic side effects. Cyclosporin A (CsA) has limited skin penetration due to its high molecular weight, so a nano-in-micro system was developed, combining CsA-loaded lipid vesicles (CsA-LVs) with dissolving microneedle array patches (DMAPs). The CsA-LVs@DMAPs exhibited sufficient mechanical strength to penetrate the stratum corneum, showed good in vitro biocompatibility, achieved effective drug retention in ex vivo skin, and reduced inflammation, histological damage, and cytokine levels in vivo. This system demonstrates potential as a targeted, corticosteroid-free therapy for skin inflammatory diseases[21].

Antonio José Guillot nov2024 et al developed a Dissolving microneedles loaded with cyanocobalamin that reduce skin inflammation in vivo Cyanocobalamin-loaded dissolving microneedle patches (B12@DMAPs) were engineered with sufficient mechanical strength to pass through the stratum corneum and deliver vitamin B12 directly into the skin. The system ensured effective intradermal deposition and showed excellent cytocompatibility with L929 fibroblasts and HaCaT keratinocytes. In a delayed-type hypersensitivity mouse model, the optimized

B12@DMAPs lowered MPO-associated photon emission, reduced tissue injury on histology, and suppressed key inflammatory cytokines[22].

Jiaxin Zhao sep24 et al developed a A wearable patch designed for controlled release of two drugs for psoriasis treatment.A wearable dual-drug synergistic release patch was created using an integrated magnesium battery and a viologen-based hydrogel that served as both the cathode and the drug-loading matrix. This system enabled controlled, on-demand co-delivery of dexamethasone and tannic acid, producing a strong synergistic anti-inflammatory effect. In a praziquimod-induced psoriasis mouse model, the low-voltage patch rapidly improved lesions and restored skin appearance within 5 days[23].

Xianbing Dai may 2024 et al developed a Trilayer dissolving microneedle patches loaded with calcipotriol nanosuspension, evaluated for in-vitro delivery and in-vivo antipsoriatic activity.Calcipotriol monohydrate (CPM) was formulated as a nanosuspension (~211 nm) and incorporated into a trilayer dissolving microneedle patch composed of poly(vinylpyrrolidone)–poly(vinyl alcohol) with a 3D-printed polylactic acid backing. The patch's dissolving tips, high mechanical strength, and efficient skin penetration enhanced CPM delivery compared to conventional ointment. In an imiquimod-induced psoriasis model, this microneedle patch achieved therapeutic outcomes comparable to the marketed Daivonex ointment, demonstrating improved local drug delivery and potential for better patient adherence Calcipotriol Nanosuspension-Loaded Trilayer Dissolving Microneedle Patches [24].

Pim Sermsaksasithorn may 2024 et al developed a Cannabis transdermal patch evaluated for efficacy and safety in alleviating psoriasis symptoms in a randomized controlled trial (CanPatch).Cannabidiol (CBD) was incorporated into transdermal patches with minimal THC for psoriasis treatment. These patches aim to target skin receptors to reverse psoriasis pathology. The study evaluates their efficacy and safety in patients with mild-to-moderate plaque-type psoriasis, assessing local severity, itch reduction, and microbiome changes over 90 days[25].

Eman Zmaily Dahmash 2024 march et al developed a Transdermal patches developed and characterized using thymoquinone-L-arginine-based polyamide nanocapsules for potential management of psoriasisThe final formulation comprised Thymoquinone (TQ)-loaded L-arginine-based polyamide (TQ/Arg-PA) nanocapsules incorporated into a transdermal patch using Eudragit E, plasticizers, and aloe vera as a penetration enhancer. The system provided prolonged TQ delivery with high entrapment efficiency (99.6%) and nanocapsules averaging 129.2 ± 18.2 nm in size. In vitro studies demonstrated sustained TQ release over 24 hours and a 42.6% increase in permeation due to aloe vera, highlighting the patch's potential as an effective, safe, and side-effect-free option for psoriasis management[26].

Pengyu Wang 2023 aug. et al developed a Topical indigo naturalis nanofibrous patch used as a transdermal botanical strategy for treating psoriatic skin.The final formulation comprised Indigo naturalis (IN) loaded into nanopatches made from poly(ε-caprolactone, PCL)/poly(ethylene oxide, PEO) at an optimized 5% PCL/PEO ratio (80:20 w/w), with 15% IN as the drug payload. The three key active components—indirubin, tryptanthrin, and indigo—exhibited controlled release, with indirubin and tryptanthrin released in bursts and indigo in a sustained, limited manner. Both in vivo and preliminary human studies demonstrated enhanced transdermal distribution of active compounds, effective reduction of epidermal hyperplasia and vascular remodeling, excellent biocompatibility, and no visible skin staining, indicating the nanopatch's therapeutic superiority over conventional ointment formulations[27].

Bhumika Kumar 2023 jun.et al developed a "Enhanced transdermal delivery of curcumin for effective management of plaque psoriasis, including design, formulation, characterization, and in vivo studies. The final formulation consisted of curcumin-loaded invasomes incorporated into a topical gel, optimized to enhance solubility and skin permeability. The optimized invasomes exhibited 85.8 ± 0.6% entrapment efficiency with a vesicle size of 302.3 ± 1.5 nm and achieved a permeation flux three times higher than plain curcumin gel.In vivo studies in BALB/c mice showed that the invasomal gel accelerated healing of psoriatic lesions compared to conventional curcumin gel, demonstrating its improved anti-psoriatic efficacy[28].

Zening Men 2022 Nov et al developed a Microneedle patch loaded with tacrolimus nanocrystals for the treatment of plaque psoriasis.The final formulation comprised tacrolimus (TAC) nanocrystals (NCs) incorporated into a sodium hyaluronate-based microneedle patch (MNP), with an average particle size of 259.6 ± 2.3 nm and sufficient mechanical strength (0.41 ± 0.06 N/needle) to penetrate psoriatic skin. The microneedles detached within 10 minutes after insertion, achieving an insertion depth of 258.8 ± 14.4 µm and six-fold higher intradermal drug retention compared to commercial ointment. In vivo pharmacodynamic studies demonstrated that the TAC NCs MNP improved both phenotypic and histopathological features of psoriasis and significantly reduced TNF-α, IL-17A, and IL-23 levels, confirming its effective anti-psoriatic activity[29].

Yik Weng Yew 2022 jan et al developed a A novel transdermal device designed for delivery of triamcinolone to treat nail psoriasis.The curcumin-loaded invasomal gel exhibited an entrapment efficiency of 85.8 ± 0.6% and a vesicle size of 302.3 ± 1.5 nm, achieving a permeation flux three times higher than that of plain curcumin gel.In vivo studies in BALB/c mice showed that the invasomal gel accelerated recovery from psoriatic lesions compared to conventional curcumin gel, demonstrating its enhanced anti-psoriatic efficacy[30].

Tao Wan march 2021 et al developed a Microneedle-assisted transdermal delivery of CRISPR-Cas9 targeting NLRP3 for synergistic therapy of inflammatory skin disorders.The final formulation consists of a dissolvable microneedle patch loaded with polymer-encapsulated Cas9 RNP targeting NLRP3 and dexamethasone-containing polymeric nanoparticles. Upon insertion, the patch rapidly dissolves, releasing both nanoformulations for transdermal co-delivery into keratinocytes and immune cells.In vivo, this system effectively disrupted subcutaneous NLRP3 inflammasomes, reduced skin inflammation, and enhanced glucocorticoid therapy in mouse models of inflammatory skin disorders, including psoriasis and atopic dermatitis [31].

III. CONCLUSION

Transdermal patch-based drug delivery systems have demonstrated substantial potential to transform the therapeutic landscape of psoriasis by addressing many limitations associated with conventional topical and systemic treatments. Psoriasis is characterized by chronic inflammation, hyperproliferation of keratinocytes, and a thickened stratum corneum, all of which hinder effective drug penetration and necessitate prolonged therapy. Traditional topical formulations often fail to achieve adequate drug concentrations within psoriatic plaques, while systemic therapies, although effective, are frequently associated with dose-related toxicity and poor patient adherence. In this context, transdermal patches provide a compelling solution by enabling localized, sustained, and controlled drug delivery directly to diseased skin.

Recent advances in patch technology, particularly microneedle-assisted and nanocarrier-integrated systems, have significantly improved transdermal drug transport across the compromised psoriatic barrier. Dissolving microneedle patches have shown the ability to painlessly bypass the stratum corneum, enhance intradermal drug deposition, and reduce systemic exposure. The incorporation of nanocarriers such as liposomes, cubosomes, mesoporous silica nanoparticles, and nanosuspensions further allows encapsulation of poorly soluble drugs, biologics, and immunomodulators, ensuring controlled release and improved stability. Importantly, several studies demonstrate that dual-drug and multi-layered patch designs can achieve rapid suppression of acute inflammation while maintaining long-term immunoregulation, thereby addressing both flare management and disease recurrence.

Preclinical and emerging clinical evidence consistently reports marked reductions in psoriatic severity scores, epidermal thickness, inflammatory cytokine levels, and immune cell infiltration following treatment with advanced transdermal patches. These systems also offer improved patient compliance due to their non-invasive nature, ease of application, and reduced dosing frequency. Furthermore, innovative wearable and stimulus-responsive patches introduce opportunities for on-demand and personalized therapy, aligning with precision medicine approaches.

Despite these promising outcomes, challenges remain in terms of scalable manufacturing, long-term safety evaluation of novel materials, and regulatory standardization. Nevertheless, ongoing technological innovation and growing clinical validation strongly support the future integration of transdermal patch systems as either standalone or adjunctive therapies for psoriasis. Overall, transdermal patches represent a safe, effective, and patient-centric platform with significant potential to improve long-term disease management and quality of life in individuals with psoriasis.

DECLERATIONS

CONSENT FOR PUBLICATION

Not applicable. The manuscript does not contain any person's/personal data.

All the figures and tables are self-generated and created by the authors, and require no third-party permission. All the data to publish is provided within the manuscript.

DATA AVAILABILITY STATEMENT

No new data were generated or analyzed in this study. Data sharing does not apply to the review article.

AVAILABILITY OF DATA AND MATERIAL

Not applicable. As this is a review article, no new data were created or analyzed. Data sharing does not apply to this article.

USE OF AI FOR DATA GENERATION

The authors declare that they have used Grammarly and Quillbot for correcting grammatical errors, paraphrasing, and other language issues. No AI tool was used for generating any data throughout the manuscript.

COMPETING INTEREST

All the authors have reviewed and confirmed the final version of the manuscript. The authors affirm that there is no competing interest or conflict.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

No animals or humans were subjected to be part of the study.

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