Crosstalk between white adipose tissue and skin: Unraveling its role in psoriasis pathogenesis (Review)

QIUHE SONG[1*], PENGFEI XU[1*], QIPENG XIAO[1], CHAOWEN ZHANG[1] and YOUSHENG MAO[1,2]

[1]Department of Dermatology, Affiliated Hospital of Jiujiang University, Jiujiang, Jiangxi 332000, P.R. China;
[2]Jiujiang Clinical Precision Medicine Research Center, Affiliated Hospital of Jiujiang University, Jiujiang, Jiangxi 332000, P.R. China

Received December 18, 2024; Accepted April 2, 2025

DOI: 10.3892/mmr.2025.13534

Abstract. Psoriasis is a chronic systemic inflammatory skin disorder characterized by hyperproliferation of keratinocytes and significant immune dysregulation. Obesity is markedly associated with psoriasis, acting as an independent risk factor that exacerbates disease severity and treatment failure, while weight-reduction interventions can improve psoriatic lesions. However, the mechanisms by which obesity promotes the onset and progression of psoriatic lesions still require further elucidation. The present comprehensive narrative review highlighted the critical role of the crosstalk between white adipose tissue (WAT) and skin in the pathogenesis of psoriasis. The expansion of WAT contributes to inflammation, epidermal proliferation and angiogenesis in skin lesions through the release of adipokines, extracellular vesicles and free fatty acids. Conversely, psoriatic lesions induce dysregulation in the inflammation and function of WAT. These findings suggested that this bidirectional communication not only explains the high prevalence of obesity among patients with psoriasis, but also highlights the importance of addressing metabolic comorbidities in treatment strategies.

Contents

Correspondence to: Dr Yousheng Mao, Department of Dermatology, Affiliated Hospital of Jiujiang University, 57 Xunyang East Road, Jiujiang, Jiangxi 332000, P.R. China
E-mail: maoyousheng1992@163.com

*Contributed equally

Key words: white adipose tissue, skin, psoriasis, inflammation, adipokines, extracellular vesicles, free fatty acids

1. Introduction

Psoriasis is a chronic systemic inflammatory skin disorder with a global prevalence of 2-3% (1). The most prevalent form, plaque psoriasis, accounts for ~90% of all cases (2). The condition is characterized by erythematous plaques covered with silvery scales, typically affecting areas such as the scalp, elbows, knees, back and buttocks. Histopathologically, psoriasis is marked by excessive proliferation of keratinocytes, leading to epidermal hyperplasia and a thickened stratum corneum (3). Inflammatory cells, primarily T lymphocytes, infiltrate the dermal papillae, while dilated capillaries contribute to the erythema (4,5). These features collectively define the characteristic appearance and symptoms of psoriasis. Three main inflammatory circuits are involved in pathogenesis of psoriatic lesions (6): i) T helper (Th) 17 and cytotoxic T cell (Tc) 17 responses driven by interleukin (IL)-17, IL-23 and C-C motif chemokine ligand (CCL) 20; ii) type I and II interferon responses driven by plasmacytoid dendritic cells (pDCs) and interferon-γ (IFN-γ)-secreting T cells, along with C-X-C motif chemokine ligand (CXCL) 9 and 10 feedback; and iii) an IL-36 and neutrophil axis driven by CXCL1, 2 and 8. Cytokines such as IL-12, IL-23 and tumor necrosis factor-α (TNF-α) collectively initiate and sustain these inflammatory circuits (6,7).

Obesity is recognized as one of the most prevalent comorbid conditions associated with psoriasis. Of patients with psoriasis ~25% are also affected by obesity (8), indicating a significant association between these two conditions. Moreover, obesity is recognized as an independent risk factor for psoriasis (9). Research has demonstrated a positive association between obesity and the severity of the disease in both human patients and murine models (10,11). Additionally, obesity may lead to higher treatment failure rates for psoriasis (12). Notably, interventions such as medications, surgery and diet control aiming at reducing fat can also improve psoriatic lesions (12-14). Consequently, obesity influences both the onset and progression of psoriasis, as well as overall prognosis.

The expansion of white adipose tissue (WAT) is a hallmark of obesity. This expansion involves various processes, including adipocyte hypertrophy and hyperplasia, the differentiation of pre-adipocytes into mature adipocytes, endothelial cell proliferation for increased vascular density, inflammatory cell infiltration, and remodeling of the extracellular matrix (15-18).

Collectively, these changes affect both the function and metabolic state of WAT. Given that WAT functions as a crucial endocrine organ, its alterations can have widespread effects on other organs and tissues, including the skin. For instance, adipose-derived adipokines can influence angiogenesis, immune responses and the maintenance of skin barrier function (19,20). Understanding these mechanisms is essential not only for elucidating the pathophysiology of skin diseases, but also for identifying potential new therapeutic targets for conditions, such as psoriasis, which are linked to obesity. Studies have also increasingly emphasized the role of the skin in modulating WAT function (21-24). Thus, understanding the crosstalk between WAT and skin is essential for unraveling the pathogenesis of skin diseases.

In light of the growing evidence on the interactions between WAT and skin in psoriasis, the aim of the present narrative review was to provide a comprehensive overview to deepen understanding of this complex relationship. This bidirectional communication not only helps explain the high prevalence of obesity among patients with psoriasis, but also highlights the critical need to address metabolic comorbidities in treatment strategies.

2. Materials and methods

To investigate the crosstalk between WAT and skin in psoriasis, a comprehensive literature search was conducted using PubMed and Google Scholar. The search employed keywords including 'adipose tissue', 'skin lesions', 'psoriasis', 'adipokines', 'extracellular vesicles', 'FFAs' and 'inflammation', focusing on studies published over the past 20 years, up to September 30, 2024. The inclusion criterion was the focus on the interaction between WAT and skin in relation to psoriasis. Studies not published in English, those lacking primary data, or reviews without new insights were excluded. Data extraction was performed independently by at least two reviewers, and any discrepancies were resolved through discussion to reach a consensus. Ethical approval was not required for the present narrative review; however, all selected studies adhered to ethical guidelines for research involving human and/or animal subjects.

3. Effect of WAT on skin during psoriasis

Overview. Over the past decade, extensive research has highlighted the role of WAT in the development of psoriatic lesions. Specifically, WAT exacerbates the severity of these lesions by increasing inflammatory levels, promoting epidermal proliferation and facilitating angiogenesis through the action of adipokines, extracellular vesicles (EVs) and free fatty acids (FFAs; Fig. 1).

Adipokines. Adipokines are bioactive molecules secreted by WAT that are essential in modulating various physiological processes, such as metabolism, inflammation and immune responses. To date, >600 adipokines have been identified and they are generally categorized into two categories, proinflammatory and anti-inflammatory (25). During the expansion of WAT, proinflammatory adipokines such as leptin, resistin, TNF-α, monocyte chemoattractant protein-1 (MCP-1), visfatin, chemerin and IL-6 are secreted in increased amounts. By contrast, anti-inflammatory adipokines such as adiponectin and C1q/tumor necrosis factor-related protein (CTRP) 3 are secreted in reduced quantities (26-28). These alterations in adipokine levels collectively contribute to increased systemic inflammation, ultimately promoting the pathological development of inflammatory diseases such as psoriasis (Fig. 2).

Adiponectin. Adiponectin, a hormone secreted by WAT, exhibits both anti-inflammatory and insulin-sensitizing effects. Its role in psoriasis is complex, involving various mechanisms related to immune cells and inflammatory pathways. In patients with psoriasis, plasma, skin and subcutaneous adiponectin levels are markedly lower than those observed in healthy individuals (29-31). Despite these diminished levels, there is a weak association between adiponectin concentrations and the severity of psoriasis, as assessed by the Psoriasis Activity Score Index (PASI) (30,32). Furthermore, clinical treatments that improve psoriasis symptoms do not seem to normalize adiponectin levels (30). This suggests that reduced adiponectin levels might be more closely associated with WAT dynamics during obesity rather than with psoriasis itself.

Animal studies provide evidence that adiponectin may play a pathogenic role in the development of psoriasis. For instance, mice lacking adiponectin show increased susceptibility to psoriasiform lesions (31). Adiponectin is considered to involve the promotion of M2 macrophage differentiation and suppression of IL-17/IL-23 production, which could help alleviate psoriatic inflammation (19,31,33). Notably, lower adiponectin levels are negatively associated with IL-23 gene expression (34). In the skin of adiponectin-deficient mice treated with imiquimod, an increase in IL-23p19 and IL-17 production has been observed (31). Conversely, administering adiponectin has been shown to inhibit IL-17 production in adiponectin-deficient mice and suppress IL-17 production from dermal γδ T cells *in vitro* (31). Additionally, a peptide derived from adiponectin, known as P5, interacts with the AdipoR1 receptor to inhibit IL-17 and mitigate imiquimod-induced psoriasiform lesions in mouse models (35,36).

Adiponectin also influences psoriasis by affecting the expression of human β-defensin 2 (hBD2), a marker involved in inflammatory pathways, and may indirectly modulate IL-23 levels (19,37). Furthermore, adiponectin promotes the expansion of regulatory T cell (Treg) populations (38). Adiponectin stimulates AMP-activated protein kinase, and this activation is associated with decreased skin thickness and reduced psoriasis severity (39,40).

Overall, the diverse functions of adiponectin indicate its potential protective role in psoriasis. However, the reduction of adiponectin due to WAT expansion diminishes its protective effects, resulting in heightened inflammation and worsening of psoriatic lesions. Future studies could consider focusing on longitudinal human data and exploring therapeutic strategies, such as AdipoR1 agonists or adiponectin mimetics, as potential approaches to address both the metabolic and inflammatory components of psoriasis.

Leptin. Leptin is a hormone produced by WAT that regulates appetite and energy balance, with its levels being associated

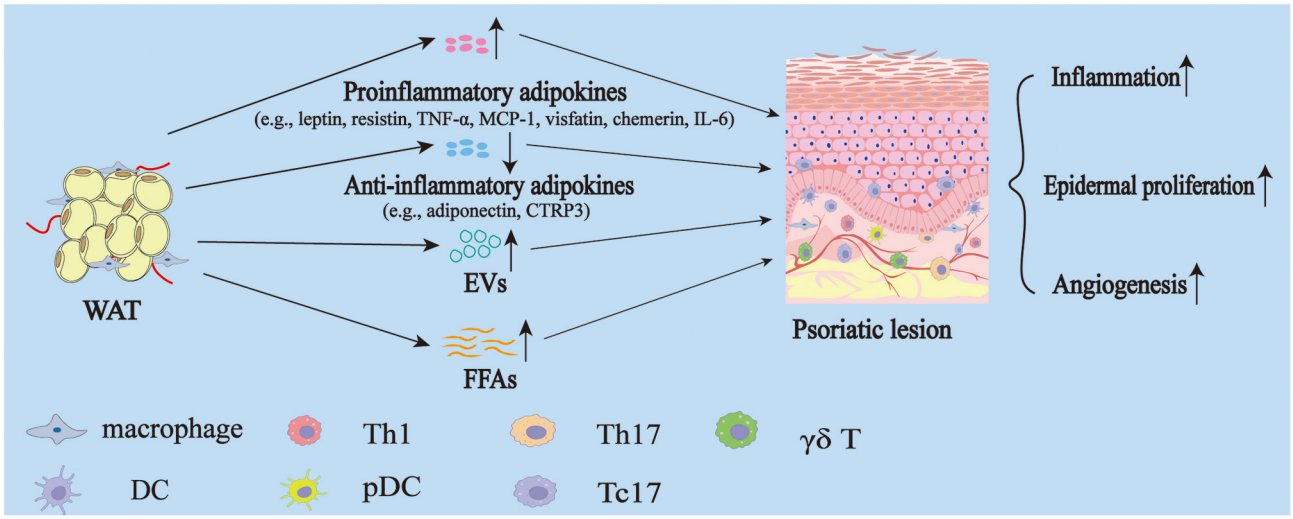

Figure 1. Effect of WAT on skin during psoriasis. In obesity, WAT undergoes expansion and functional alterations, resulting in increased secretion of proinflammatory adipokines such as leptin, resistin, TNF-α, MCP-1, visfatin, chemerin, IL-6 and others, and decreased secretion of anti-inflammatory adipokines such as adiponectin, CTRP3 and others. Additionally, WAT exhibits elevated levels of EVs and FFAs. The secretion of these bioactive molecules contributes to the promotion of inflammation, epidermal hyperproliferation and angiogenesis in psoriatic lesions. WAT, white adipose tissue; TNF-α, tumor necrosis factor-α; MCP-1, monocyte chemoattractant protein-1; IL, interleukin; CTRP, C1q/tumor necrosis factor-related protein; EVs, extracellular vesicles; FFAs, free fatty acids; Th, T helper; DC, dendritic cell; pDC, plasmacytoid dendritic cell; Tc, cytotoxic T cell.

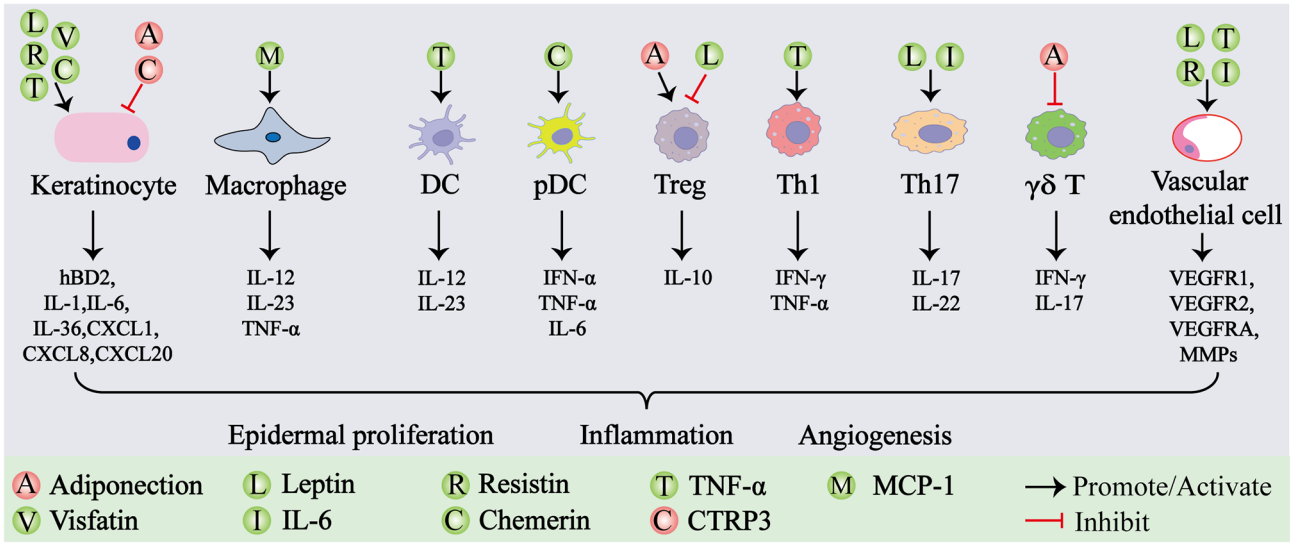

Figure 2. Effect of adipokines on psoriatic lesions. Different adipokines can modulate the quantity and function of various cell types within psoriatic lesions, thereby influencing the expression levels of cytokines. Ultimately, the combined effects of these cytokines and dysfunctional cells lead to the clinical manifestation of psoriatic lesions, characterized by excessive epidermal proliferation, inflammation and angiogenesis. Red balls labeled with different letters represent distinct anti-inflammatory adipokines. Green balls labeled with different letters represent distinct proinflammatory adipokines. TNF-α, tumor necrosis factor-α; MCP-1, monocyte chemoattractant protein-1; IL, interleukin; CTRP, C1q/tumor necrosis factor-related protein; Treg, regulatory T cell; Th, T helper; DC, dendritic cell; pDC, plasmacytoid dendritic cell; hBD2, human β-defensin 2; CXCL, C-X-C motif chemokine ligand; IFN, interferon; VEGFR, vascular endothelial growth factor receptor; VEGFA, vascular endothelial growth factor A; MMPs, matrix metalloproteinases.

with fat stores and involvement in inflammatory diseases such as psoriasis. Elevated leptin levels are commonly observed in the plasma and skin of patients with psoriasis, particularly in severe cases, and these levels are associated with disease severity as indicated by the PASI (29,41,42). The primary contribution of leptin to psoriasis lies in its ability to enhance inflammation by stimulating the production of proinflammatory cytokines, including IL-1, IL-6, CXCL8 and TNF-α, which are pivotal in driving the inflammatory response (19,43). This cascade promotes a Th1/Th17 immune response, leading to increased levels of IL-17 and IL-23, which exacerbate the characteristic symptoms of the disease (44,45).

Leptin also modulates immune cell function by promoting the differentiation of Th17 cells. This effect is mediated through the upregulation of retinoic acid receptor-related orphan receptor γ t, a key transcription factor involved in Th17 cell development, thereby contributing to the accumulation of IL-17 (46). Moreover, leptin reduces the numbers and functionality of Tregs, diminishing their production of IL-10 and further exacerbating inflammation (47). Anti-leptin

monoclonal antibodies have been shown to enhance Treg proliferation, while leptin receptor antagonists can increase Foxp3 expression and inhibit IL-17 production, highlighting the role of leptin in immune regulation (19,48,49). Furthermore, leptin activates the Janus kinase (JAK)/signal transducer and activator of transcription 3 (STAT3) signaling pathway, which amplifies the inflammatory response and promotes angiogenesis in psoriatic lesions, thereby supporting ongoing inflammation and disease progression (50).

In keratinocytes, leptin influences proliferation and function by stimulating the release of amphiregulin, a growth factor that accelerates keratinocyte proliferation, contributing to the hyperproliferation observed in psoriatic lesions (51). Additionally, leptin upregulates the expression of chemokines such as CXCL8, CXCL1 and CCL20, further stimulating keratinocyte proliferation and inflammation (52). It acts synergistically with IL-17A to enhance the expression of these chemokines and hBD2 through mitogen-activated protein kinase (MAPK) and JAK2 pathways, leading to impaired keratinocyte maturation and excessive expression of disease-related genes (19,53).

In summary, leptin serves a critical mediating role in WAT and psoriatic lesions by promoting inflammatory responses, enhancing immune cell activity, influencing keratinocyte proliferation and maturation, and promoting angiogenesis. These actions collectively exacerbate the pathological progression of psoriasis. Future research should further explore the heterogeneity of leptin signaling pathways in specific patient subgroups, such as obese and non-obese individuals, and assess the clinical translational potential of targeting leptin.

Resistin. In rodents, resistin is primarily produced by WAT, while in humans it is mainly secreted by immune and epithelial cells. Although WAT is not the primary source of resistin in humans, its production in WAT increases during obesity (43,54). Elevated levels of resistin have been observed in patients with psoriasis and are positively associated with disease severity (29,55). The role of resistin in psoriasis initiates through its binding to Toll-like receptor (TLR) 4 and cysteine-rich ankle-like protein 1 receptors, activating crucial signaling pathways such as nuclear factor κB (NF-κB) (56,57). This activation induces the production of proinflammatory cytokines such as TNF-α, IL-6 and IL-1β, which play a central role in the inflammatory cascade observed in psoriasis (58). As a result, immune cell recruitment to the skin is promoted, exacerbating inflammation (2,58).

Furthermore, resistin directly influences keratinocyte behavior, which is crucial for the development of psoriatic lesions. It activates the NF-κB and Phosphoinositide 3-kinase/Protein kinase B (PI3K/AKT) signaling pathways, leading to the upregulation of genes associated with cell cycle progression and survival, such as human telomerase reverse transcriptase and caveolin-1 (56,59,60). This process results in increased keratinocyte proliferation and impaired differentiation, contributing to the formation and persistence of psoriatic lesions. Additionally, resistin affects cellular apoptosis, disrupting the balance necessary for maintaining skin homeostasis. By inhibiting apoptosis pathways, such as PI3K/AKT and MAPK/Extracellular Signal-Regulated Kinase, resistin leads to increased keratinocyte survival and impaired turnover, further exacerbating plaque development (56,61).

Finally, resistin promotes angiogenesis in psoriatic lesions by activating signaling pathways that enhance endothelial cell proliferation and modulate the expression of angiogenesis-related genes and chemokines, including vascular endothelial growth factor (VEGF) receptor (VEGFR) 1, VEGFR2, VEGFA and matrix metalloproteinases (56,62).

To conclude, resistin serves a critical mediating role in WAT and psoriatic lesions by promoting inflammatory responses, enhancing immune cell activity, influencing keratinocyte proliferation and maturation, and promoting angiogenesis. These actions collectively exacerbate the pathological progression of psoriasis. Future studies could evaluate the potential of metabolic interventions, such as weight loss or insulin-sensitizing treatments, in jointly regulating resistin levels and psoriasis pathology.

TNF-α. TNF-α, a proinflammatory adipokine, is markedly upregulated during the expansion of WAT and exerts widespread effects on various tissues through endocrine and paracrine mechanisms. Increased concentrations of TNF-α are frequently observed in the plasma and skin of patients with psoriasis, and are associated with disease severity (55,63). TNF-α is vital in establishing the inflammatory milieu of psoriatic lesions, initiating and sustaining the disease process through complex interactions among various cell types and signaling pathways. It activates DCs, resulting in increased production of IL-12, which facilitates the differentiation of naive T cells into Th1 cells (6,64,65). These Th1 cells then produce notable amounts of IFN-γ and TNF-α, amplifying the inflammatory response and creating a feedback loop that exacerbates the condition (63).

Additionally, TNF-α directly affects keratinocytes, inducing their hyperproliferation and increasing the production of proinflammatory cytokines such as IL-1, IL-6 and CXCL8, along with NF-κB (65,66). It also upregulates adhesion molecules such as E-selectin, P-selectin and intercellular adhesion molecule-1, facilitating the recruitment of immune cells into psoriatic lesions (65,67). Furthermore, TNF-α collaborates with IL-17A, stabilizing IL-17A mRNA and enhancing IL-17 receptor expression on keratinocytes, which increases the cellular response to IL-17A (68). This interaction sustains an inflammatory cascade, as IL-17A also promotes the expression of TNF receptors (6,69).

Moreover, TNF-α influences angiogenesis in psoriatic lesions by inducing the secretion of VEGF, promoting new blood vessel formation (66). This contributes to the increased vascularity observed in psoriatic lesions, further supporting the ongoing inflammatory process.

To summarize, TNF-α is a central mediator in psoriasis, orchestrating a complex network of immune cell activation, cytokine production, keratinocyte proliferation and angiogenesis, all of which drive the chronic inflammation and lesion formation characteristic of the disease. Although TNF-α inhibitors have shown marked efficacy in the treatment of psoriasis, the mechanisms of resistance in some patients remain unclear. Future research should further investigate the synergistic effects of TNF-α targeted therapy and metabolic interventions, such as glucagon-like peptide-1 receptor agonists, to

improve both skin symptoms and systemic metabolic function and inflammation levels in patients.

Other adipokines. In addition to the aforementioned adipokines, several other adipokines have been identified as being expressed at high levels in expanded WAT and have been extensively studied for their roles and mechanisms in psoriatic lesions.

MCP-1 levels are increased in the serum and skin of patients with psoriasis (70,71). MCP-1 contributes to psoriasis by promoting the migration and activation of macrophages in the skin, thereby driving inflammation. This process involves MCP-1 working in conjunction with TNF-α to initiate and sustain the inflammatory environment, influencing immune cell recruitment, and maintaining the inflammatory cycle in psoriatic lesions (70). Visfatin levels are also increased in the serum of patients with psoriasis, showing a positive association with disease severity (72). Visfatin amplifies the inflammatory responses in keratinocytes triggered by TNF-α by upregulating CXCL8, CXCL10, CCL20 and antimicrobial peptides (73,74). Additionally, serum chemerin concentrations are elevated in patients with psoriasis (75). Chemerin exacerbates psoriasis by promoting the migration of pDCs to psoriatic lesions, activating NF-κB, and upregulating proinflammatory cytokines such as TNF-α, IL-6 and CXCL8 (19,76). Furthermore, chemerin increases keratin 16 expression, which is associated with keratinocyte proliferation and contributes to psoriasis pathogenesis (77). Elevated levels of IL-6 have also been observed in the plasma and skin of patients with psoriasis, and these levels are associated with disease severity as indicated by PASI (63,78). IL-6 contributes to psoriatic lesions by promoting Th17 cell differentiation, inhibiting the suppressive functions of Tregs and inducing angiogenesis through the upregulation of VEGF production (63).

In psoriasis, reduced levels of adipocyte-derived CTRP3 in the blood lead to decreased anti-inflammatory effects, as CTRP3 typically exerts its protective role through the lysosomal-associated membrane protein 1-STAT3 axis, mitigating inflammation in the skin lesions (79).

In conclusion, various adipokines, including MCP-1, visfatin, chemerin, IL-6 and CTRP3, play notable roles in psoriasis by influencing inflammation, immune cell dynamics, keratinocyte proliferation and angiogenesis. These adipokines interact within a complex network that affects disease severity and progression. Further investigation is required to clarify the synergistic roles of these adipokines in the development of psoriatic lesions.

EVs. EVs are tiny membrane-bound particles released by cells into the extracellular environment. They can be categorized into four primary types: i) Exosomes; ii) apoptotic bodies; iii) microvesicles; and iv) oncosomes (80). EVs are vital for intercellular communication, transporting proteins, lipids and nucleic acids that influence various biological processes, including immune responses, disease progression and potential therapeutic strategies (81).

In obese patients, the levels of EVs in peripheral blood are markedly higher compared with those in healthy individuals, contributing to increased systemic inflammation (82). EVs derived from WAT primarily contain adipokines such as IL-6, MCP-1, adiponectin and resistin (82,83). Given that these adipokines are widely involved in the inflammatory response associated with psoriatic lesions, it is hypothesized that adipose-derived EVs also play a role in the pathological development of psoriasis. Furthermore, EVs derived from WAT in obesity contain a single-exon circular RNA known as circ_0075932, which can promote inflammation by activating the NF-κB pathway in the skin (84).

Notably, exosomes derived from mesenchymal stem cells of healthy WAT have been shown to suppress local inflammation in psoriatic lesions and improve clinical symptoms (85). This finding supports the notion that WAT can interact with the skin through EVs. The differences in the composition of EVs released by WAT under various conditions may represent a critical regulatory factor in the pathological changes observed in psoriatic lesions. However, research on the role of EVs in mediating crosstalk between WAT and skin remains limited. Further studies are needed to elucidate the role of EVs in the onset, progression and resolution of psoriatic lesions.

FFAs. During the expansion of WAT, FFAs increase due to enhanced lipolysis from adipocyte, reflecting marked metabolic changes (86). Elevated serum FFA levels, particularly saturated FFAs, are associated with the severity of skin lesions in both patients and mice models (87,88). An *in vitro* study showed that FFAs sensitize DCs, enhancing the secretion of cytokines during proinflammatory stimulation (89).

Additionally, FFAs directly stimulate the secretion of key inflammatory cytokines, including IL-1β and IL-23 from TLR-activated myeloid cells (90). Notably, dermal γδ T cells, which are implicated in psoriatic lesions, exhibit higher lipid content and uptake than their IFN-γ-producing counterparts. This suggests that FFAs not only enhance inflammatory signaling, but also favor the differentiation and accumulation of pathogenic T cells (91).

Moreover, the preferential uptake of elevated levels of long-chain FFAs by Tregs leads to cellular mitochondrial dysfunction, oxidative stress and lipotoxicity (92). This ultimately reduces the population of Tregs and is associated with diminished regulation of dermal γδ T cell-mediated inflammation, exacerbating the inflammatory response associated with psoriatic lesions (92).

Collectively, the expansion of WAT can facilitate the pathological progression of psoriatic lesions through elevated levels of FFAs, suggesting that targeting FFA metabolism may offer promising therapeutic avenues for managing psoriasis and its associated inflammatory responses in the future.

4. Effect of skin on WAT during psoriasis

While extensive research has focused on the effects of WAT on the skin, studies investigating the role and mechanisms by which the skin regulates WAT remain limited. Under physiological conditions, the skin has been shown to participate in the development and proliferation of dermal WAT as demonstrated in mouse models (24,47).

In psoriasis, heightened inflammation in psoriatic lesions can provoke inflammatory responses in the underlying subcutaneous adipose tissue (SAT), leading to increased expression of microRNA (miR)-26b-5p in this tissue, which results in

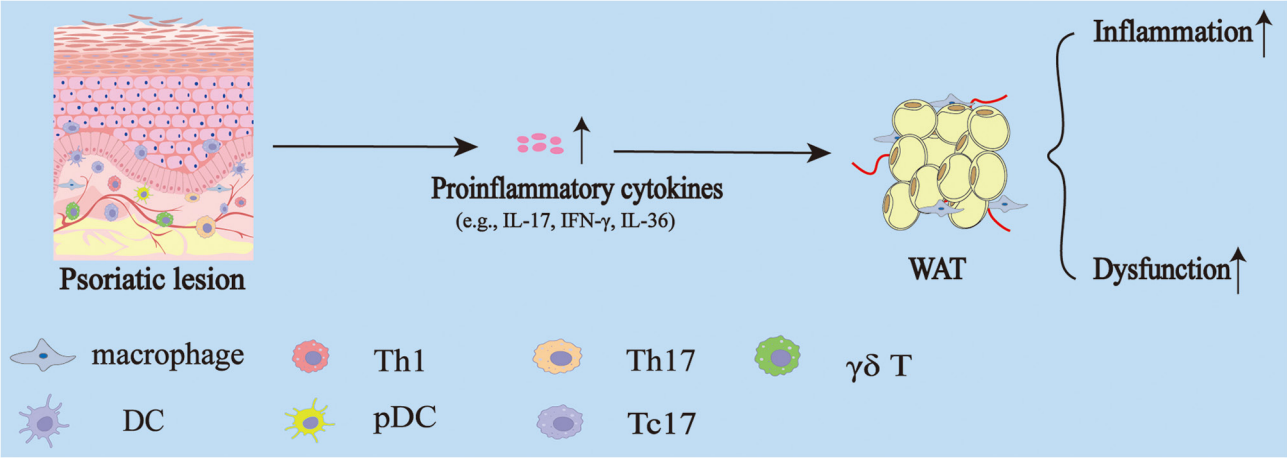

Figure 3. Effect of skin on WAT during psoriasis. In psoriatic lesions, there is a marked infiltration of inflammatory cells, which produce a variety of pro-inflammatory cytokines, such as IL-17, IFN-γ, IL-36 and others. These cytokines, through paracrine and endocrine mechanisms, ultimately lead to elevated levels of inflammation and functional impairment of WAT. WAT, white adipose tissue; IL, interleukin; IFN, interferon; Th, T helper; DC, dendritic cell; pDC, plasmacytoid dendritic cell; Tc, cytotoxic T cell.

functional defects in cholesterol efflux (21,93). Additionally, the disruption of the skin barrier and thermoregulatory functions caused by psoriatic lesions may promote the browning of SAT (94).

Beyond localized effects, psoriatic lesions may also facilitate systemic expansion of WAT, potentially contributing to obesity. This occurs through the release of proinflammatory cytokines into the bloodstream (94). Cytokines essential to the inflammatory pathways in psoriasis such as IL-17, IFN-γ and IL-36 are expressed at elevated levels in the lesion (6). Studies have indicated that these cytokines are also found in increased concentrations in the serum of affected patients (95,96). Evidence suggests that IL-17, IFN-γ and IL-36 can promote inflammatory cell infiltration and the release of inflammatory factors in WAT (23,97,98). Consequently, these cytokines, which are expressed at high levels in psoriatic lesions, serve as a communication bridge between skin and WAT. Conversely, a study involving transgenic mice which overexpressed caspase-1 specific to keratin 14 and exhibited systemic skin inflammation showed visceral WAT atrophy (22). While this model does not accurately reflect the inflammatory changes seen in psoriasis, it highlights the complexity of the relationship between skin inflammation and WAT.

In brief, psoriatic lesions can induce inflammation and dysfunction in WAT through both paracrine and endocrine mechanisms (Fig. 3). Future research should aim to elucidate the specific regulatory effects and molecular mechanisms by which psoriatic lesions influence WAT.

5. Discussion and conclusions

Current research has revealed notable crosstalk between WAT and skin lesions in psoriasis. This interaction plays a critical role in driving inflammatory progression, epidermal hyperproliferation and local angiogenesis in skin lesions. On the other hand, skin lesions exacerbate inflammation and dysfunction in WAT by upregulating inflammatory factors. Despite these insights, several key aspects of this complex relationship remain underexplored.

First, most existing studies have primarily focused on the role of adipokines in mediating communication between WAT and skin. However, the mechanisms through which EVs and lipids influence the effects of WAT on skin lesions are largely unexplored and require further investigation. Second, current research often examines individual molecules or pathways in isolation, lacking a comprehensive, integrated analysis of the way multiple molecules interact to regulate the pathogenesis of psoriasis through synergistic or antagonistic effects. Furthermore, research has mainly concentrated on the unidirectional regulation of psoriatic lesions by WAT, while the feedback effects of psoriatic lesions on WAT remodeling and systemic metabolism lack systematic analysis. Additionally, the differential impact of WAT from different anatomical sites such as subcutaneous compared with visceral fat on psoriasis has not been clearly defined in current studies. The dynamic changes in WAT-skin interactions across different stages of psoriasis (acute compared with chronic) also remain unclear. Finally, while intervention strategies targeting adipokines or lipid metabolism have shown promise in animal models, there is a lack of large-scale clinical trials to validate their efficacy and safety.

In the future, the field of WAT-skin crosstalk in psoriasis still holds immense research potential, warranting continued attention. A key area of focus should be the application of systems biology approaches, integrating multi-omics data to explore in greater depth the way various molecules originating from WAT interact within complex networks to collectively drive the development and progression of psoriasis. Furthermore, applications of novel models, such as the transgenic zebrafish model developed for dynamic monitoring of adipocytes (99), will enhance research into the interactions between WAT and skin. Additionally, conducting targeted clinical trials to evaluate the impact of obesity treatments, such as semaglutide, on improving skin lesions in obese patients with psoriasis is of great importance. In addition, given the potential therapeutic value of exosomes in disease management, developing engineered exosomes based on the secretion profile of healthy WAT holds significant research and clinical promise. Lastly, a promising direction for future research involves developing novel targeted

drugs based on key molecules involved in the WAT-skin interaction mechanism, with the potential for clinical application.

In conclusion, the present narrative review offered a comprehensive analysis of the latest advances in understanding the molecular mechanisms driving the bidirectional communication between WAT and skin in psoriasis. The expansion of WAT contributes to inflammation, epidermal proliferation, and angiogenesis in skin lesions through the release of adipokines, EVs, and FFAs. Conversely, psoriatic lesions induce dysregulation in the inflammation and function of WAT. These mechanistic insights carry significant clinical implications: Comorbidity management through metabolic interventions could synergize with conventional anti-psoriatic therapies to address both cutaneous and systemic inflammation. Furthermore, lifestyle integration emphasizing weight management and dietary interventions should be prioritized in treatment protocols, given the cyclical relationship between adiposity and psoriatic severity. By adopting this dual-focused therapeutic paradigm that concurrently targets cutaneous and metabolic pathologies, clinicians may achieve improved long-term outcomes while mitigating metabolic risks in patients with psoriasis.

Acknowledgements

Not applicable.

Funding

The current study was funded by the National Natural Science Foundation of China (grant no. 82260283).

Availability of data and materials

Not applicable.

Authors' contributions

QS was responsible for data curation, funding acquisition and writing the original draft. PX was responsible for data curation, formal analysis, visualization and writing the original draft. QX was responsible for investigation and writing the original draft. CZ was responsible for methodology and writing the original draft. YM was responsible for conceptualization, project administration, resources, supervision, validation, writing the original draft and writing, reviewing and editing. All authors have read and approved the final version of the manuscript. Data authentication is not applicable.

Ethics approval and consent to participate

Not applicable.

Patient consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

References

1. Greb JE, Goldminz AM, Elder JT, Lebwohl MG, Gladman DD, Wu JJ, Mehta NN, Finlay AY and Gottlieb AB: Psoriasis. Nat Rev Dis Primers 2: 16082, 2016.
2. Boehncke WH and Schön MP: Psoriasis. Lancet 386: 983-994, 2015.
3. Fülle M, Metze D, Böer-Auer A, Osada N and Braun SA: Psoriasis on the leg: Site-specific histopathological and immuno-histochemical features and diagnostic difficulties. Acta Derm Venereol 101: adv00453, 2021.
4. Ma F, Plazyo O, Billi AC, Tsoi LC, Xing X, Wasikowski R, Gharaee-Kermani M, Hile G, Jiang Y, Harms PW, *et al*: Single cell and spatial sequencing define processes by which keratinocytes and fibroblasts amplify inflammatory responses in psoriasis. Nat Commun 14: 3455, 2023.
5. Han Q, Niu X, Hou R, Li J, Liu Y, Li X, Li J, Li Y, Zhang K and Wu Y: Dermal mesenchymal stem cells promoted adhesion and migration of endothelial cells by integrin in psoriasis. Cell Biol Int 45: 358-367, 2021.
6. Griffiths CEM, Armstrong AW, Gudjonsson JE and Barker JNWN: Psoriasis. Lancet 397: 1301-1315, 2021.
7. Singh R, Koppu S, Perche PO and Feldman SR: The cytokine mediated molecular pathophysiology of psoriasis and its clinical implications. Int J Mol Sci 22: 12793, 2021.
8. Alajroush WA, Alrshid AI, Alajlan AH, Alsalamah YB, Alhumaidan MI, Alhoumedan AI, Alrasheed MI, Alowairdhi YA, Alowirdi F, Aljoufi AZ, *et al*: Psoriasis and metabolic disorders: A comprehensive meta-analysis of million adults worldwide. Cureus 16: e52099, 2024.
9. Budu-Aggrey A, Brumpton B, Tyrrell J, Watkins S, Modalsli EH, Celis-Morales C, Ferguson LD, Vie GÅ, Palmer T, Fritsche LG, *et al*: Evidence of a causal relationship between body mass index and psoriasis: A mendelian randomization study. PLoS Med 16: e1002739, 2019.
10. Leite BF, Morimoto MA, Gomes C, de Carvalho Klemz BN, de Souza Genaro P, Damasceno NRT, Szejnfeld VL and de Medeiros Pinheiro M: Higher bodily adiposity, fat intake, and cholesterol serum levels are associated with higher disease activity in psoriatic arthritis patients: Is there a link among fat and skin and joint involvement? Lipids Health Dis 19: 21, 2020.
11. Park SH, Lee KA, Choi JH, Park S, Kim DW and Jung SY: Impact of obesity on the IL-6 immune marker and Th17 immune cells in C57BL/6 mice models with imiquimod-induced psoriasis. Int J Mol Sci 24: 5592, 2023.
12. Paroutoglou K, Papadavid E, Christodoulatos GS and Dalamaga M: Deciphering the association between psoriasis and obesity: Current evidence and treatment considerations. Curr Obes Rep 9: 165-178, 2020..
13. Malavazos AE, Meregalli C, Sorrentino F, Vignati A, Dubini C, Scravaglieri V, Basilico S, Boniardi F, Spagnolo P, Malagoli P, *et al*: Semaglutide therapy decreases epicardial fat inflammation and improves psoriasis severity in patients affected by abdominal obesity and type-2 diabetes. Endocrinol Diabetes Metab Case Rep 2023: 23-0017, 2023.
14. Corbetta S, Angioni R, Cattaneo A, Beck-Peccoz P and Spada A: Effects of retinoid therapy on insulin sensitivity, lipid profile and circulating adipocytokines. Eur J Endocrinol 154: 83-86, 2006.
15. Horwitz A and Birk R: Adipose tissue hyperplasia and hypertrophy in common and syndromic obesity-the case of BBS obesity. Nutrients 15: 3445, 2023.
16. Corvera S, Solivan-Rivera J and Loureiro ZY: Angiogenesis in adipose tissue and obesity. Angiogenesis 25: 439-453, 2022.
17. Kawai T, Autieri MV and Scalia R: Adipose tissue inflammation and metabolic dysfunction in obesity. Am J Physiol Cell Physiol 320: C375-C391, 2021.
18. Ruiz-Ojeda FJ, Méndez-Gutiérrez A, Aguilera CM and Plaza-Díaz J: Extracellular matrix remodeling of adipose tissue in obesity and metabolic diseases. Int J Mol Sci 20: 4888, 2019.
19. Kiełbowski K, Bakinowska E, Ostrowski P, Pala B, Gromowska E, Gurazda K, Dec P, Modrzejewski A and Pawlik A: The role of adipokines in the pathogenesis of psoriasis. Int J Mol Sci 24: 6390, 2023.
20. Guan J, Feng J, Xu M, Liu M, He Y and Lu F: Adipokines-enriched adipose extract restores skin barrier and ameliorates inflammatory dysregulation in an atopic dermatitis mouse model. Plast Reconstr Surg 154: 701e-712e, 2023.

21. Caton PW, Evans EA, Philpott MP and Hannen RF: Can the skin make you fat? A role for the skin in regulating adipose tissue function and whole-body glucose and lipid homeostasis. Curr Opin Pharmacol 37: 59-64, 2017.
22. Mizutani K, Shirakami E, Ichishi M, Matsushima Y, Umaoka A, Okada K, Yamaguchi Y, Watanabe M, Morita E and Yamanaka K: systemic dermatitis model mice exhibit atrophy of visceral adipose tissue and increase stromal cells via skin-derived inflammatory cytokines. Int J Mol Sci 21: 3367, 2020.
23. Pestel J, Chehimi M, Bonhomme M, Robert M, Vidal H and Eljaafari A: IL-17A contributes to propagation of inflammation but does not impair adipogenesis and/or insulin response, in adipose tissue of obese individuals. Cytokine 126: 154865, 2020.
24. Ueyama T, Sakuma M, Nakatsuji M, Uebi T, Hamada T, Aiba A and Saito N: Rac-Dependent signaling from keratinocytes promotes differentiation of intradermal white adipocytes. J Invest Dermatol 140: 75-84.e6, 2020.
25. Kovács D, Fazekas F, Oláh A and Törőcsik D: Adipokines in the skin and in dermatological diseases. Int J Mol Sci 21: 9048, 2020.
26. Hwang J, Yoo JA, Yoon H, Han T, Yoon J, An S, Cho JY and Lee J: The role of leptin in the association between obesity and psoriasis. Biomol Ther (Seoul) 29: 11-21, 2021.
27. Soujanya KV and Jayadeep AP: Obesity-associated biochemical markers of inflammation and the role of grain phytochemicals. J Food Biochem 46: e14257, 2022.
28. Wolf RM, Steele KE, Peterson LA, Magnuson TH, Schweitzer MA and Wong GW: Lower circulating C1q/TNF-related protein-3 (CTRP3) levels are associated with obesity: A cross-sectional study. PLoS One 10: e0133955, 2015.
29. Słuczanowska-Głabowska S, Staniszewska M, Marchlewicz M, Duchnik E, Łuczkowska K, Safranow K, Machaliński B and Pawlik A: Adiponectin, leptin and resistin in patients with psoriasis. J Clin Med 12: 663, 2023.
30. Gerdes S, Pinter A, Biermann M, Papavassilis C and Reinhardt M: Adiponectin levels in a large pooled plaque psoriasis study population. J Dermatolog Treat 31: 531-534, 2020.
31. Shibata S, Tada Y, Hau CS, Mitsui A, Kamata M, Asano Y, Sugaya M, Kadono T, Masamoto Y, Kurokawa M, *et al*: Adiponectin regulates psoriasiform skin inflammation by suppressing IL-17 production from γδ-T cells. Nat Commun 6: 7687, 2015.
32. Gerdes S, Osadtschy S, Rostami-Yazdi M, Buhles N, Weichenthal M and Mrowietz U: Leptin, adiponectin, visfatin and retinol-binding protein-4-mediators of comorbidities in patients with psoriasis? Exp Dermatol 21: 43-47, 2012.
33. Oh J, Lee Y, Oh SW, Li T, Shin J, Park SH and Lee J: The role of adiponectin in the skin. Biomol Ther (Seoul) 30: 221-231, 2022.
34. Kochumon S, Hasan A, Al-Rashed F, Sindhu S, Thomas R, Jacob T, Al-Sayyar A, Arefanian H, Al Madhoun A, Al-Ozairi E, *et al*: Increased adipose tissue expression of IL-23 associates with inflammatory markers in people with high LDL cholesterol. Cells 11: 3072, 2022.
35. Ohn J, Been KW, Kim JY, Kim EJ, Park T, Yoon HJ, Ji JS, Okada-Iwabu M, Iwabu M, Yamauchi T, *et al*: Discovery of a transdermally deliverable pentapeptide for activating AdipoR1 to promote hair growth. EMBO Mol Med 13: e13790, 2021.
36. Suh JH, Lee Y, Ohn J, Kim EJ, Kim TG, Jo SJ, Kim SJ and Chung JH: Adiponectin-derived pentapeptide ameliorates psoriasiform skin inflammation by suppressing IL-17 production in γδT cells. J Dermatol Sci 106: 45-52, 2022.
37. Jin T, Sun Z, Chen X, Wang Y, Li R, Ji S and Zhao Y: Serum human beta-defensin-2 is a possible biomarker for monitoring response to JAK inhibitor in psoriasis patients. Dermatology 233: 164-169, 2017.
38. Tsang JYS, Li D, Ho D, Peng J, Xu A, Lamb J, Chen Y and Tam PKH: Novel immunomodulatory effects of adiponectin on dendritic cell functions. Int Immunopharmacol 11: 604-609, 2011.
39. D'Amico F, Costantino G, Salvatorelli L, Ramondetta A, De Pasquale R, Sortino MA and Merlo S: Inverse correlation between the expression of AMPK/SIRT1 and NAMPT in psoriatic skin: A pilot study. Adv Med Sci 67: 262-268, 2022.
40. Shen H, Sha Y, Huang J, Mao AQ, Zhang T, Wu MY, Sun F, Yu YY, Cheng ZQ and Gong YT: The roles of AMPK-mediated autophagy and mitochondrial autophagy in a mouse model of imiquimod-induced psoriasis. Am J Transl Res 13: 12626-12637, 2021.
41. Wang R, Yu C, Tang Z, Sun J, Wang Y, Zhao Z, Lin B and Li C: Leptin induces altered differentiation of keratinocytes by inducing insulin resistance: Implications for metabolic syndrome-induced resistance of psoriatic therapy. J Dermatolog Treat 35: 2309305, 2024.
42. Zhu KJ, Zhang C, Li M, Zhu CY, Shi G and Fan YM: Leptin levels in patients with psoriasis: A meta-analysis. Clin Exp Dermatol 38: 478-483, 2013.
43. Johnston A, Arnadottir S, Gudjonsson JE, Aphale A, Sigmarsdottir AA, Gunnarsson SI, Steinsson JT, Elder JT and Valdimarsson H: Obesity in psoriasis: Leptin and resistin as mediators of cutaneous inflammation. Br J Dermatol 159: 342-350, 2008.
44. Su X, Cheng Y and Chang D: The important role of leptin in modulating the risk of dermatological diseases. Front Immunol 11: 593564, 2020.
45. Su X, Zhang G, Cheng Y and Wang B: Leptin in skin disease modulation. Clin Chim Acta 516: 8-14, 2021.
46. Yu Y, Liu Y, Shi FD, Zou H, Matarese G and La Cava A: Cutting edge: Leptin-induced RORγt expression in CD4+ T cells promotes Th17 responses in systemic lupus erythematosus. J Immunol 190: 3054-3058, 2013.
47. Walendzik K, Kopcewicz M, Bukowska J, Panasiewicz G, Szafranska B and Gawronska-Kozak B: The transcription factor FOXN1 regulates skin adipogenesis and affects susceptibility to diet-induced obesity. J Invest Dermatol 140: 1166-1175.e9, 2020.
48. De Rosa V, Procaccini C, Calì G, Pirozzi G, Fontana S, Zappacosta S, La Cava A and Matarese G: A key role of leptin in the control of regulatory T cell proliferation. Immunity 26: 241-255, 2007.
49. Wang W, Zhang BT, Jiang QL, Zhao HQ, Xu Q, Zeng Y, Xu JY and Jiang J: Leptin receptor antagonist attenuates experimental autoimmune thyroiditis in mice by regulating Treg/Th17 cell differentiation. Front Endocrinol (Lausanne) 13: 1042511, 2022.
50. Calautti E, Avalle L and Poli V: Psoriasis: A STAT3-centric view. Int J Mol Sci 19: 171, 2018.
51. Markaki A, Gkouskou K, Stylianou K, Dermitzaki E, Perakis K, Margioris A and Daphnis E: Relationship between adiposity, adipokines, inflammatory markers and lipid profile in hemodialysis patients. Eur Rev Med Pharmacol Sci 18: 1496-1498, 2014.
52. Ikeda K, Morizane S, Akagi T, Hiramatsu-Asano S, Tachibana K, Yahagi A, Iseki M, Kaneto H, Wada J, Ishihara K, *et al*: Obesity and dyslipidemia synergistically exacerbate psoriatic skin inflammation. Int J Mol Sci 23: 4312, 2022.
53. Kanda N and Watanabe S: Leptin enhances human beta-defensin-2 production in human keratinocytes. Endocrinology 149: 5189-5198, 2008.
54. Khanna D, Khanna S, Khanna P, Kahar P and Patel BM: Obesity: A chronic low-grade inflammation and its markers. Cureus 14: e22711, 2022.
55. Žužul K, Kunjko K, Milošević M, Tončić RJ, Kelava T and Hadžavdić SL: The association between the severity of psoriasis and obesity based on the analysis of visceral fat index and serum levels of tumor necrosis factor-α, interleukin-6, and resistin. Acta Dermatovenerol Croat 30: 8-17, 2022.
56. Srikanth M and Rasool M: Resistin-A plausible therapeutic target in the pathogenesis of psoriasis. Immunol Invest 53: 115-159, 2024.
57. Shao S, Fang H, Dang E, Xue K, Zhang J, Li B, Qiao H, Cao T, Zhuang Y, Shen S, *et al*: Neutrophil extracellular traps promote inflammatory responses in psoriasis via activating epidermal TLR4/IL-36R crosstalk. Front Immunol 10: 746, 2019.
58. Taouis M and Benomar Y: Is resistin the master link between inflammation and inflammation-related chronic diseases? Mol Cell Endocrinol 533: 111341, 2021.
59. Mahmoud MA, Mohamed RW, Attia FM, Atwa MA and Abdel-Moneim SM: Expression of telomerase reverse transcriptase in psoriatic lesional skin. Dis Markers 22: 265-269, 2006.
60. Zhang F, Li H, Zhou Y, Gu Y and Wang L: Caveolin-1 expression in different types of psoriatic lesions: Analysis of 66 cases. Indian J Dermatol 59: 225-229, 2014.
61. Huang TH, Lin CF, Alalaiwe A, Yang SC and Fang JY: Apoptotic or antiproliferative activity of natural products against keratinocytes for the treatment of psoriasis. Int J Mol Sci 20: 2558, 2019.
62. Chen SS, Tang CH, Chie MJ, Tsai CH, Fong YC, Lu YC, Chen WC, Lai CT, Wei CY, Tai HC, *et al*: Resistin facilitates VEGF-A-dependent angiogenesis by inhibiting miR-16-5p in human chondrosarcoma cells. Cell Death Dis 10: 31, 2019.
63. Sieminska I, Pieniawska M and Grzywa TM: The immunology of psoriasis-current concepts in pathogenesis. Clin Rev Allergy Immunol 66: 164-191, 2024.
64. Jang DI, Lee AH, Shin HY, Song HR, Park JH, Kang TB, Lee SR and Yang SH: The role of tumor necrosis factor alpha (TNF-α) in autoimmune disease and current TNF-α inhibitors in therapeutics. Int J Mol Sci 22: 2719, 2021.

65. Man AM, Orăsan MS, Hoteiuc OA, Olănescu-Vaida-Voevod MC and Mocan T: Inflammation and psoriasis: A comprehensive review. Int J Mol Sci 24: 16095, 2023.
66. Patel AB, Tsilioni I, Weng Z and Theoharides TC: TNF stimulates IL-6, CXCL8 and VEGF secretion from human keratinocytes via activation of mTOR, inhibited by tetramethoxyluteolin. Exp Dermatol 27: 135-143, 2018.
67. Tan JK, Aphale A, Malaviya R, Sun Y and Gottlieb AB: Mechanisms of action of etanercept in psoriasis. J Investig Dermatol Symp Proc 12: 38-45, 2007.
68. Johansen C, Funding AT, Otkjaer K, Kragballe K, Jensen UB, Madsen M, Binderup L, Skak-Nielsen T, Fjording MS and Iversen L: Protein expression of TNF-alpha in psoriatic skin is regulated at a posttranscriptional level by MAPK-activated protein kinase 2. J Immunol 176: 1431-1438, 2006.
69. de Alcantara CC, Reiche EMV and Simão ANC: Cytokines in psoriasis. Adv Clin Chem 100: 171-204, 2021.
70. Behfar S, Hassanshahi G, Nazari A and Khorramdelazad H: A brief look at the role of monocyte chemoattractant protein-1 (CCL2) in the pathophysiology of psoriasis. Cytokine 110: 226-231, 2018.
71. Purzycka-Bohdan D, Nedoszytko B, Zabłotna M, Gleń J, Szczerkowska-Dobosz A and Nowicki RJ: Chemokine profile in psoriasis patients in correlation with disease severity and pruritus. Int J Mol Sci 23: 13330, 2022.
72. Chyl-Surdacka KM, Bartosińska J, Kowal M, Przepiórka-Kosińska J, Krasowska D and Chodorowska G: Assessment of visfatin concentrations in the serum of male psoriatic patients in relation to metabolic abnormalities. Adv Clin Exp Med 29: 79-84, 2020.
73. Hau CS, Kanda N, Noda S, Tatsuta A, Kamata M, Shibata S, Asano Y, Sato S, Watanabe S and Tada Y: Visfatin enhances the production of cathelicidin antimicrobial peptide, human β-defensin-2, human β-defensin-3, and S100A7 in human keratinocytes and their orthologs in murine imiquimod-induced psoriatic skin. Am J Pathol 182: 1705-1717, 2013.
74. Kanda N, Hau CS, Tada Y, Tatsuta A, Sato S and Watanabe S: Visfatin enhances CXCL8, CXCL10, and CCL20 production in human keratinocytes. Endocrinology 152: 3155-3164, 2011.
75. Chyl-Surdacka KM, Gerkowicz A, Bartosińska J, Kowal M, Przepiórka-Kosińska J, Surdacki G, Krasowska D and Chodorowska G: Analysis of serum chemerin concentrations in psoriatic patients in relation to metabolic abnormalities. Postepy Dermatol Alergol 36: 531-537, 2019.
76. Wang Y, Huo J, Zhang D, Hu G and Zhang Y: Chemerin/ChemR23 axis triggers an inflammatory response in keratinocytes through ROS-sirt1-NF-κB signaling. J Cell Biochem 120: 6459-6470, 2019.
77. Zhang X, Yin M and Zhang LJ: Keratin 6, 16 and 17-critical barrier alarmin molecules in skin wounds and psoriasis. Cells 8: 807, 2019.
78. Lynch M, Ahern T, Sweeney CM, Malara A, Tobin AM, O'Shea D and Kirby B: Adipokines, psoriasis, systemic inflammation, and endothelial dysfunction. Int J Dermatol 56: 1103-1118, 2017.
79. Xue K, Shao S, Fang H, Ma L, Li C, Lu Z and Wang G: Adipocyte-derived CTRP3 exhibits anti-inflammatory effects via LAMP1-STAT3 axis in psoriasis. J Invest Dermatol 142: 1349-1359.e8, 2022.
80. Wang K and Zeng C: Extracellular vesicles and obesity. Adv Exp Med Biol 1418: 143-153, 2023.
81. Jeppesen DK, Zhang Q, Franklin JL and Coffey RJ: Extracellular vesicles and nanoparticles: Emerging complexities. Trends Cell Biol 33: 667-681, 2023.
82. Kumar V, Kiran S, Kumar S and Singh UP: Extracellular vesicles in obesity and its associated inflammation. Int Rev Immunol 41: 30-44, 2022.
83. Kranendonk MEG, Visseren FLJ, van Herwaarden JA, Nolte-'t Hoen ENM, de Jager W, Wauben MHM and Kalkhoven E: Effect of extracellular vesicles of human adipose tissue on insulin signaling in liver and muscle cells. Obesity (Silver Spring) 22: 2216-2223, 2014.
84. Zhang X, Chen L, Xiao B, Liu H and Su Y: Circ_0075932 in adipocyte-derived exosomes induces inflammation and apoptosis in human dermal keratinocytes by directly binding with PUM2 and promoting PUM2-mediated activation of AuroraA/NF-κB pathway. Biochem Biophys Res Commun 511: 551-558, 2019.
85. Meybodi MA, Nilforoushzadeh MA, KhandanDezfully N and Mansouri P: The safety and efficacy of adipose tissue-derived exosomes in treating mild to moderate plaque psoriasis: A clinical study. Life Sci 353: 122915, 2024.
86. Nussbaumerova B and Rosolova H: Obesity and dyslipidemia. Curr Atheroscler Rep 25: 947-955, 2023.
87. Saalbach A, Seitz AT, Kohlmann J, Kalweit L, Vogt L, Selig L, Engel KM and Simon JC: Modulation of dietary fatty acids in an open-label study improves psoriasis and dampens the inflammatory activation status. Nutrients 15: 1698, 2023.
88. Herbert D, Franz S, Popkova Y, Anderegg U, Schiller J, Schwede K, Lorz A, Simon JC and Saalbach A: High-Fat diet exacerbates early psoriatic skin inflammation independent of obesity: Saturated fatty acids as key players. J Invest Dermatol 138: 1999-2009, 2018.
89. Stelzner K, Herbert D, Popkova Y, Lorz A, Schiller J, Gericke M, Klöting N, Blüher M, Franz S, Simon JC and Saalbach A: Free fatty acids sensitize dendritic cells to amplify TH1/TH17-immune responses. Eur J Immunol 46: 2043-2053, 2016.
90. Mogilenko DA, Haas JT, L'homme L, Fleury S, Quemener S, Levavasseur M, Becquart C, Wartelle J, Bogomolova A, Pineau L, *et al*: Metabolic and innate immune cues merge into a specific inflammatory response via the UPR. Cell 177: 1201-1216.e19, 2019.
91. Lopes N, McIntyre C, Martin S, Raverdeau M, Sumaria N, Kohlgruber AC, Fiala GJ, Agudelo LZ, Dyck L, Kane H, *et al*: Distinct metabolic programs established in the thymus control effector functions of γδ T cell subsets in tumor microenvironments. Nat Immunol 22: 179-192, 2021.
92. Sivasami P, Elkins C, Diaz-Saldana PP, Goss K, Peng A, Hamersky M IV, Bae J, Xu M, Pollack BP, Horwitz EM, *et al*: Obesity-induced dysregulation of skin-resident PPARγ+ Treg cells promotes IL-17A-mediated psoriatic inflammation. Immunity 56: 1844-1861.e6, 2023.
93. Cheung L, Fisher RM, Kuzmina N, Li D, Li X, Werngren O, Blomqvist L, Ståhle M and Landén NX: Psoriasis skin inflammation-induced microRNA-26b targets NCEH1 in underlying subcutaneous adipose tissue. J Invest Dermatol 136: 640-648, 2016.
94. Zhu T, Yang S, Mauro TM and Man MQ: Association of epidermal biophysical properties with obesity and its implications. Skin Pharmacol Physiol 36: 165-173, 2023.
95. Arican O, Aral M, Sasmaz S and Ciragil P: Serum levels of TNF-alpha, IFN-gamma, IL-6, IL-8, IL-12, IL-17, and IL-18 in patients with active psoriasis and correlation with disease severity. Mediators Inflamm 2005: 273-279, 2005.
96. Sehat M, Talaei R, Dadgostar E, Nikoueinejad H and Akbari H: Evaluating serum levels of IL-33, IL-36, IL-37 and gene expression of IL-37 in patients with psoriasis vulgaris. Iran J Allergy Asthma Immunol 17: 179-187, 2018.
97. Sharma N, Akkoyunlu M and Rabin RL: Macrophages-common culprit in obesity and asthma. Allergy 73: 1196-1205, 2018.
98. Frühbeck G, Gómez-Ambrosi J, Ramírez B, Mentxaka A, Rodríguez A, Becerril S, Reina G, Valentí V, Moncada R, Silva C and Catalán V: Corrigendum: Increased levels of interleukin-36 in obesity and type 2 diabetes fuels adipose tissue inflammation by inducing its own expression and release by adipocytes and macrophages. Front Immunol 14: 1138316, 2023.
99. Mao Y, Hong KH, Liao W, Li L, Kim SJ, Xiong Y, Nam IK, Choe SK and Kwak SA: Generation of a novel transgenic zebrafish for studying adipocyte development and metabolic control. Int J Mol Sci 22: 3994, 2021.