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# The Role of Microbiota in Atopic Dermatitis

**Desiana Widityaning Sari[1], Nur Annisa Nugraheningtyasari[2]**
[1]Faculty of Medicine and Health, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia
[2]Department of Internal Medicine, Dr. Soetomo General Academic Hospital, Surabaya, Indonesia, Faculty of Medicine Universitas Airlangga, Surabaya, Indonesia

*Corresponding Author: desiana@its.ac.id*

***Abstract*** — Skin microbiota play an important role in the pathogenesis of AD. Damage to the integrity of the skin mucosa allows penetration of allergens and colonization of the skin by pathogenic microorganisms. This can then stimulate inflammation related to excessive activation of Th2 lymphocytes throughout the body including the digestive tract and respiratory tract. The understanding of the latest definition of AD emphasizes this disease as a chronic inflammatory disease characterized by disruption of the skin barrier, inflammation, and dysbiosis (an imbalance between commensal and pathogenic bacteria, which then has significant health implications). Skin dysbiosis is based on an increase in the concentration of *Staphylococcus aureus* colonization, which causes a decrease in the number of commensal bacteria. Changes in the microbiota in AD affect the functioning of the immune system, stimulating inflammatory reactions that are manifested as atopic eczema. This concept of dysbiosis is important to discuss because it can influence new strategies for the treatment and prevention of AD. This article will further discuss the role of microbiota in AD.

***Keywords*** — Atopic dermatitis; Microbiota; Skin

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## INTRODUCTION

Atopic Dermatitis (AD) is a chronic, recurrent inflammatory disease characterized by dry skin accompanied by pruritus [1]. The onset of this disease often begins in early childhood, AD usually appears as the first manifestation of a series of symptoms called the allergic march, namely a group of atopic symptoms such as asthma, allergic rhinitis, and allergic conjunctivitis [2].

The etiopathogenesis of AD is very complex and is related to genetic and environmental factors that can induce abnormal immune responses. Inflammation in AD is associated with the dominance of CD4 lymphocyte differentiation through the Th2 stimulation pathway. Increased Th2 lymphocyte activity will further stimulate the production of cytokines, especially interleukin (IL)-4, IL-5, and IL-13, as well as decreased interferon (IFN)-γ synthesis. Th2 cells can also secrete IL-22 which plays an important role in the initiation of the acute phase of AD [3], while the transition to a Th1/Th17 response transforms the disease into a chronic inflammatory process [4].

## ATOPIC DERMATITIS

Atopic dermatitis (AD) is a chronic, recurrent inflammatory skin disease characterized by itching and lesions often called eczema. The distribution and morphological characteristics are generally age-related. Although most often manifested during the first year of life, the disease can occur at any age. Children with AD are more susceptible to develop other atopic diseases than children without AD, and AD can be the initial form of the development of other atopic manifestations later in life (food allergy, asthma, and allergic rhinitis) known as the “allergic march” [5].

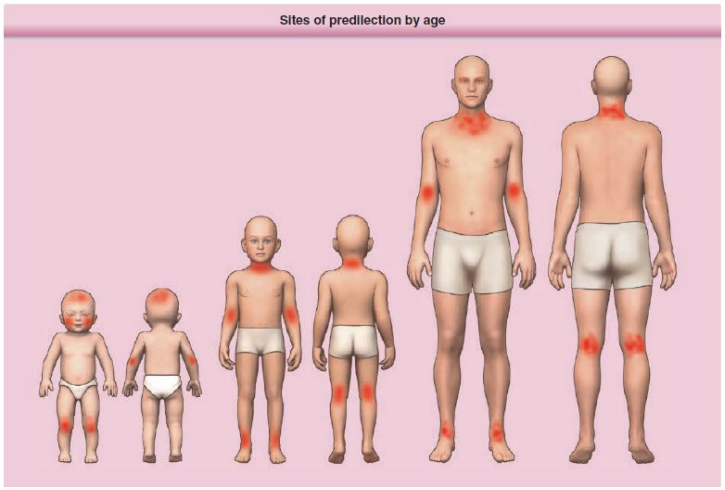


**Fig. 1.** AD distribution based on age: infancy, childhood, and adulthood [6].

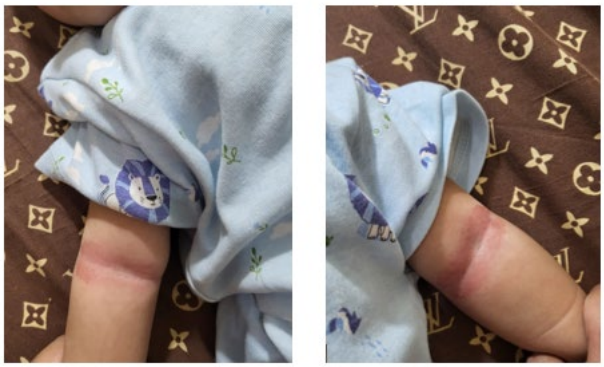

**Fig. 2.** Red macules in both antecubital fossae in a child.

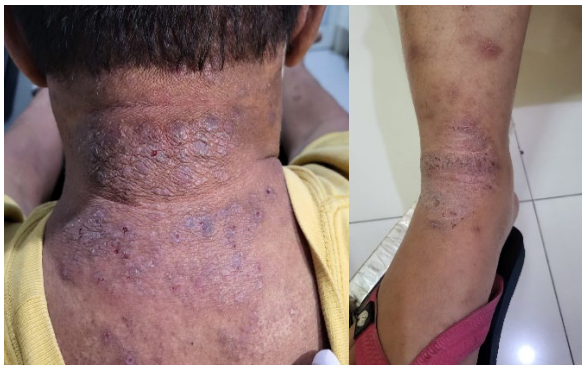

**Fig. 3.** Lichenification in neck and flexural fold of AD in adult.

Many risk factors are associated with the development of AD, ranging from genetic predisposition to environmental conditions. A family history of atopic disease is the most prominent risk factor for AD. Several environmental risk factors have been suggested to increase the prevalence of AD, such as low UV light exposure, dry climate, diet, and repeated exposure to antibiotics in early childhood [7]. The pathophysiology of AD is complex and has not been fully elucidated. Multiple contributing factors, including epidermal barrier damage, immune dysregulation, and changes in the skin microbiota, contribute to the disease [5].

*1. Epithelial Barrier Dysfunction and Immune Dysregulation*

The skin plays a major role in protecting against penetration of commensals and pathogens. Several factors contribute to epithelial barrier dysfunction in AD, including mutations in genes encoding structural and functional proteins of the epidermis. Filaggrin is one of the key epidermal proteins for producing natural moisturizing factors and is essential for maintaining the hydration of the stratum corneum. Mutations in the filaggrin gene have been found in patients with moderate to severe disease. Deficiency in filaggrin production also results in aberrant keratinocyte differentiation and inadequate skin lipid content. Skin lipids (e.g., ceramides, free fatty acids, and cholesterol) are essential for the maintenance of epidermal barrier function and are thus responsible for preventing Trans-epidermal Water Loss (TEWL) and penetration of irritants, allergens, and microbes [8].

Epithelial barrier disruption will also cause keratinocytes to release cytokines that cause leukocyte infiltration, especially dendritic cells, eosinophils, and T cells. Th2 cell initiation will release IL-4, IL-5, and IL-13, as well as decreased IFN-γ synthesis. Th2 cells can also secrete IL-22 which has an important role in the initiation of the acute phase of AD [3], while the transition to a Th1/Th17 response transforms the disease into a chronic inflammatory process [4].

*2. Skin Microbiota Dysbiosis*

The skin of patients with AD shows significant abnormalities in the microbiota community when compared to the microbiota of healthy subjects. However, it is not yet clear whether these changes are the cause or the consequence of epidermal barrier dysfunction and immune dysregulation. The skin in AD is characterized by microbiota imbalance and reduced diversity, which is specifically manifested by a decrease in *Cutibacterium, Streptococcus, Acinetobacter, Corynebacterium,* and *Prevotella* bacteria, and a marked increase in *Staphylococcus*, especially *Staphylococcus aureus* [9]. In a recent study, it was discovered that *Staphylococcus aureus* colonized the skin of 57% to 100% of children and 54% to 100% of adults with AD. The pooled prevalence of *Staphylococcus aureus* among patients was 70% for lesional skin and 39% for non-lesional skin, according to another comprehensive study on the prevalence of *Staphylococcus aureus* in AD. The frequency of *Staphylococcus aureus* colonization was also increasing with AD severity. Additionally, *Staphylococcal* species like *Staphylococcus epidermidis* and *Staphylococcus hominis* (*coagulase-negative Staphylococcus* [CoNS]) that secrete antibiotics or encourage the secretion of antimicrobial peptides (AMPs) to defend healthy skin from invasive pathogens are less common in AD patients. Reintroducing these antibiotic CoNS strains to AD patients decreases *Staphylococcus aureus* colonization, indicating that skin microbiome dysbiosis plays a role in the illness. Through virulence factors such as superantigens (toxins), enzymes, and other proteins, *Staphylococcus aureus* colonization on AD skin disrupts the skin barrier and permits allergen presentation to epidermal dendritic cells, which intensifies AD symptoms. By maintaining the integrity of the epidermis and providing efficient defense against infections, the cutaneous microbiota supports the function of the skin barrier. Atopic dermatitis (AD), a chronic inflammatory illness linked to abnormalities in the skin barrier, is often characterized by dysbiosis. In the event of several local AD-specific characteristics, such as decreased skin acidity, facilitated bacterial adherence, and decreased synthesis of antimicrobial peptides, dysbiosis is linked to decreased bacterial diversity and noticeable *Staphylococcus aureus* colonization. Additionally, by changing the epidermal barrier and triggering an inflammatory response, *Staphylococcus aureus* -associated skin dysbiosis may possibly contribute to the immunopathology of AD through the generation of staphylococcal virulence factors. Nevertheless, there are currently no justifications for suggesting that *Staphylococcus aureus* -associated dysbiosis be screened for and treated outside of cutaneous superinfection. However, altering the skin microbiome might be a promising treatment for AD [10]. In a longitudinal prospective study, the skin microbiomes of children with moderate-to-severe AD and healthy children were examined. The skin microbiome disparities between the two groups and the number of *Staphylococcus aureus* in the AD patients decreased as the severity of the disease improved with bleach baths, progressively approaching that of healthy controls [11].

## SKIN MICROBIOTA IN ATOPIC DERMATITIS

The skin is the largest organ of the human body, forming a protective layer that prevents infection by pathogens from the environment. Human skin can also be considered as an ecosystem, where different parts of the body represent different habitats for microbiota. Commensal microorganisms that inhabit the skin can prevent the colonization of pathogenic microorganisms, thereby helping to maintain the balance of immune system activation from effective protection to destructive inflammation [12]. Commensal microorganisms provide protective effects in various ways, for example, *Staphylococcus epidermidis* can produce antimicrobial substances to fight pathogenic microorganisms, and *Cuticabacterium acnes* can use skin lipid content to produce short-chain fatty acids that can limit the development of pathogenic microorganisms. *Cutibacterium* and *Corynebacterium sp*. can also reduce the number of *Staphylococcus aureus* colonies, which play an important role in influencing the severity of AD [13]. The diversity of the human skin microbiome varies depending on many factors, including body region, age, and gender [12,14]. Bacterial phyla that can be found on healthy human skin are *Cutibacterium, Streptococcus, Acinetobacter, Prevotella, and Corynebacterium* with *Propionibacterium* accounting for more than 60% of the skin bacterial population. Dry areas (forearms, buttocks, hands) are the most diverse skin areas, more diverse than the gut or oral cavity, and harbor many phylotypes including *Proteobacteria* and *Corynebacteria.* Moist areas of the skin (nostrils, armpits, navel, internodes of the toes, groin, cubital and popliteal fossae, palms and soles) provide a warm environment, with *Corynebacterium* and *Staphylococci* species being the most abundant organisms. The sebaceous area (forehead, retro auricular, back) shows the lowest bacterial diversity and is predominantly inhabited by *Propionibacterium* species and lipophilic Staphylococci [15].

Monitoring the profile of microorganisms inhabiting the skin is essential in AD patients. In most cases, *Staphyloccocus aureus* culture results are often found positive in AD patients and these individuals are susceptible to skin infections, especially in the exacerbation phase of the disease. *Staphyloccocus aureus* strains isolated from AD patients secrete various damaging exotoxins. These toxins can act as superantigens with strong immunostimulant properties, inducing specific IgE synthesis and damaging the skin barrier [14].

The effect of treatment on *Staphyloccocus aureus* colonization in the exacerbation phase is also a major topic of frequent research. Ultraviolet phototherapy has been shown to reduce *Staphyloccocus aureus* colonization of atopic skin and reduce the production of these bacterial toxins. Seite et al. confirmed that the skin microbiota became more diverse after AD treatment, which may be related to the maintenance of the remission phase of skin lesions [16]. Several literature reviews reported that the use of probiotics containing *Bifidobacterium sp.* can reduce the degree of pruritus, because these bacteria when supplied to the body through probiotic supplementation will colonize the skin competitively and suppress the growth of *Staphylococcus aureus* and other pathogenic microorganisms. It is important to realize that the skin condition of AD patients can also be affected by clothing. Tight and damp clothing can encourage the growth of anaerobic bacteria so patients are recommended to wear clothes made of cotton/linen to prevent exacerbation of the disease [17].

## GUT MIKROBIOTA IN ATOPIC DERMATITIS

The gut microbiota also plays an important role in the etiopathogenesis of AD. The composition of the gastrointestinal microflora differs at each stage of human life. Therefore, the emergence of AD in childhood may be associated with problems that occur during the formation of the microbiome at that age. Many studies have confirmed the protective effects of *Bifidobacterium* and *Bacteroides* in the intestine. These bacteria are protective and can prevent colonization of the intestine by pathogenic microorganisms. Based on this, the presence of *Bifidobacterium* and *Bacteroides* or their deficiency may have a direct impact and contribute to AD symptoms [18].

The newborn's gastrointestinal tract is initially sterile but will be colonized soon after birth. The route of delivery and the time of contact with the microflora of the maternal genital tract play an important role in this colonization process. The diet during the first days of life (breast milk vs. formula milk) also has a major impact on the infant's gut microbiome and immunity. Lee et al. confirmed that intestinal bacterial colonization in infancy is closely related to the development of the immune system and intestinal microflora dysbiosis can precede the onset of atopic disease [19]. Several studies have shown that infants with AD have low intestinal microflora diversity, characterized by low levels of *Bifidobacterium* and *Bacteroides* and high levels of *Enterobacteriaceae* [20]. Lee et al. showed that in patients with AD, the proportion of *Clostridium* bacteria (including *Clostridium difficile*), *E. coli* and *Staphylococcus aureus* in the intestinal microbiome was higher than in healthy controls [19]. Other findings suggest an interaction between the intestinal microflora and the skin microbiome. *Staphylococcus aureus* is the most common pathogen that can be found in skin cultures of AD patients, but a recent cohort study showed that intestinal colonization by *Staphylococcus aureus* was negatively associated with the development of AD in infancy. Although *Staphylococcus aureus* colonization of the skin can worsen AD, this does not rule out the possibility that colonization of the intestinal mucosa by *Staphylococcus aureus* before the atopic march may be protective [21].

Microbes from birth colonize the human gut; a healthy gut contains bacteria from the genera *Bacillus, Lactobacillus, Clostridium, and Ruminococcus*. The gut microbiome has several roles, including collecting indigestible food particles in feces and absorbing vitamins and minerals, as well as working with the liver to detoxify and get rid of xenobiotics, which are toxic foreign substances that are all over the place. Although host health depends on a healthy stomach, skin diseases can arise from overgrowth and changes in the variety of the gut microbiome. As mentioned in the preceding paragraphs, several metabolic by-products of gut bacteria have the direct ability to affect both normal physiology and disease processes. There are three types of factors that affect the diversity of the gut microbial community: bacterial factors (like microbial enzymes and adhesive ability), host factors (like pancreatic enzymes, bile acids, and pH), and non-host factors (like environmental determinants). Free phenol, p-cresol, and derivatives of aromatic amino acids are thought to be biomarkers of gut dysbiosis, which has a detrimental effect on skin health. The three common skin conditions that are caused by dysbiosis in the gut are psoriasis, atopic dermatitis, and acne. Additionally, certain less frequent but possibly more significant conditions like rosacea, alopecia areata, hidradenitis suppurativa, erythema nodosum, and pyoderma gangrenosum have been linked to intestinal dysbiosis. Several microbial species from the human gut that have been associated with skin effects are *Faecalibacterium prausnitzii, Akkemansia muciniphila* and *Ruminococcus* which give protection against psoriasis. *Lactobacillus casei* and *Lactobacillus paracasei* was proven to decrease skin inflammation and reduce the size of acne lesions as well as inflammation by altering the number of cytotoxic CD8+ T cells and inhibiting mast cell degranulation, TNF-α release, and vasodilation, and also edema and vasodilation. *Bifidobacterium animalis* subsp. *lactis* [LKM512] can reduce the scratching behavior in atopic dermatitis by increasing of levels of the kynurenic and metabolite [22].

The gut microbiome can modulate blood cytokine levels and indirectly affect the function of the nervous system and stress conditions of an individual. Cortisol is released under stress conditions and can alter the permeability of the intestinal epithelium, thereby modifying the function of the intestinal barrier which in turn alters the composition of the gut microbiome. Cortisol also alters circulating neuroendocrine molecules such as tryptamine, trimethylamine, and serotonin, thereby altering the condition of the skin barrier and the inflammatory response of the skin. Sugar levels are also very important in terms of colonization of a particular group of microorganisms. In diabetic patients, infections with the etiology of *Staphylococcus aureus* and *Candida sp*. are very common. The sugar content in food intake can also increase the development of several groups of bacteria such as *Escherichia coli* in the intestine and cause serious changes in the condition of the gut microbiome. In contrast, a proper diet, rich in vegetables and fruits, contributes to the growth of beneficial commensal bacteria such as the *Bacteroides*

group [19]. Several studies have shown that antibiotic therapy can disrupt the composition of the gut and skin microbiome, resulting in dysbiosis. After antibiotic use, the microbiome rebuilds its colonies within about 2 years, but in terms of biodiversity, the microbiome will never return to normal [23]. Repeated and long-term use of antibiotics in childhood is often associated with the development of AD. Several possibilities such as early changes in the skin, which are misdiagnosed as infections, are treated with antibiotics, then lead to disruption of the microbiota balance and as a consequence, colonization of pathogens. AD sufferers also often suffer from respiratory problems and antibiotics are often prescribed when a respiratory infection is suspected with simple symptoms such as cough/cold [19].

## ATOPIC DERMATITIS THERAPY

The management approach for AD is based on severity, age, and location. One effective therapy for AD is the administration of emollients. Routine use of emollients can reduce the severity of symptoms and improve skin hydration. Emollients also affect the presence of *Staphylococcus* and the diversity of skin microbiota. The administration of petrolatum and ceramide-based lipid creams is also said to reduce TEWL and colonization of pathogenic bacteria, thereby improving skin barrier function [24].

In the acute phase of the disease, the administration of topical steroids as first-line anti-inflammatories is recommended, but it should be noted that long-term use can cause side effects. In the early 21$^{st}$ century, topical calcineurin inhibitors were introduced as a substitute for topical steroids. Tacrolimus and pimecrolimus are calcineurin inhibitors that prevent T-cell signal transduction and IL-2 transcription, thereby suppressing inflammation. Tacrolimus has also shown a positive impact on the skin microbiome of AD patients [25]. Antibiotics are included in the treatment of AD in cases of bacterial superinfection, but due to antibiotic resistance and the potential negative effects of antibiotics on commensal bacteria, this treatment method is not a long-term option. Another therapeutic option is ultraviolet phototherapy. Phototherapy B narrow band is said to be able to reduce the number of Staphylococcus aureus on the skin [26].

## PREBIOTICS, PROBIOTICS AND SYNBIOTICS

The condition of the microbiome has a major impact on a person's health so it needs to be modified. This is based on the fact that the development of a disease is not only caused by the colonization of pathogenic bacteria but also by the deficiency of commensal microorganisms. The microbiome can be manipulated through the use of probiotics. This agent acts as an immunomodulator. However, it should be noted that probiotics, whether applied or taken orally, only colonize the intestines or skin during the treatment period. Studies show that after discontinuation of therapy, probiotic strains are only detected for a short time [27]. The relationship between factors that affect the microbiome in AD patients is still being studied to this day, including the effectiveness of using prebiotics or probiotics in AD treatment regimens.

### *Probiotics*

Probiotics are live bacteria with immunomodulatory features that are considered beneficial to human health. Although most probiotics are targeted at gastrointestinal disorders, recent reports have recognized the great potential of probiotics to improve skin health. Orally administered probiotics interact with the gut microflora, while topical probiotics work by modulating the skin microflora [28]. Commonly used probiotic families are the gram-positive bacteria *Bifidobacterium* and *Lactobacillus.* Probiotics modulate the immune system by stimulating the differentiation of regulatory T cells and regulating the production of anti-inflammatory cytokines (TGF-β and IL-10). TGF-β has been shown to improve the integrity of the skin epithelial barrier and reduce TEWL. In addition, *Lactobacillus* can also accelerate skin reconstruction and inhibit skin inflammation.

*Bifidobacterium* bacteria are also known to have antipruritic effects [28]. Most studies confirm that single-strain probiotic supplementation during pregnancy (especially *Lactobacillus rhamnosus*) can prevent the development of AD in high-risk infants. Kwon et al. in his study showed that *Lactobacillus rhamnosus* taken by pregnant women can prevent the development of AD in half of the population of children in high-risk groups up to the age of 2 years with stabilization up to the age of 4 years, while in babies who were given *Bifidobacterium lactis* or *Lactobacillus rhamnosus* resulting in the development of milder forms of AD [26]. In 2015, the World Allergy Organization (WAO) recommended the use of probiotics in pregnant women, especially in the last 3 months of pregnancy, and in breastfeeding women, especially in infant populations at high risk for AD [30]. Despite the many studies supporting the use of probiotics to prevent the development of AD, the issue of treating atopy with probiotics is still a debate to date. Some recent research evidence suggests that single-strain probiotic preparations are not always effective when compared to multi-strain probiotics and prebiotics. A randomized double-blind placebo study conducted in Poland on about 60 children with cow's milk allergy manifesting as AD showed significant improvement in AD conditions with multi-strain probiotics (*Lactobacillus rhamnosus ŁOCK 0900*, *L. rhamnosus ŁOCK 090*8 and *L. casei ŁOCK 0918*) in some patients [31]. A study conducted by Prakoeswa et all in 2017 at an dermatology outpatient clinic, 30 adults with mild to moderate AD participated in a randomized, double-blind, placebo-controlled study that compared the microencapsulated probiotic (2 × 1010 CFU/day) and placebo (skim milk-Avicel). The patients were split into two groups, intervention and control, each consisting of 15 individuals. In the eighth week, the probiotic group's SCORAD score was noticeably lower than that of the placebo group. The probiotic group's levels of IL-4 and IL-17 were noticeably lower than those of the placebo group. The probiotic group's levels of Foxp3+ and IFN-γ were considerably greater than those of the placebo group. The IgE levels, however, stayed mostly unaltered [32]. As evidenced by a drop in SCORAD and levels of serum IgE, IL-4, and IL-17 as well as an increase in the Foxp3+ to IL-10 ratio, probiotic L. plantarum IS-10506 demonstrated the capacity to lessen clinical symptoms in children with AD. The probiotic's ability to reduce clinical symptoms by downregulating Th2 adaptive immune response but not upregulating Th1 adaptive immune response was a significant finding of this study. By inducing immunological tolerance, probiotics L. plantarum IS-10506 may be able to prevent the recurrence or the development of chronic AD in children who are unable to avoid allergic substances and focus on alternative therapy [33].

A meta-analysis study consisting of 6 Randomized Control Trials (RCTs) (n=241) showed that probiotics were effective in reducing the severity of AD symptoms as evidenced by lower-scoring Atopic Dermatitis (SCORAD) and improving the quality of life of patients [34]. Another meta-analysis study described that AD treatment may benefit from probiotic supplements. To enhance the therapeutic impact of probiotics for AD, the effect can be customized based on factors such as age, probiotic strain, length of probiotic intake, geographic location, ethnicity, or lifestyle [35].

Although further research is still needed, the results shown in many studies guarantee the potential of probiotics as a therapy in the management of AD. However, it should be noted that the development of live biotherapeutic products is faced with many scientific, clinical, and regulatory challenges. The current requirements for a particular type of product are not specifically defined at the global level so the acceptance criteria for product efficacy and safety are often unclear. The most obvious problem arises when considering the basic requirement of a pharmaceutical product, namely its sterility, which this therapy cannot achieve. The manufacture of this product is also complex because many factors related to product stability (viability, shelf life, genetic stability) can affect the nature of the bacteria, thus changing the efficacy or safety of the product. Determining the safety of live biotherapeutic products is different from other drugs because they do not reach the systemic circulation, while their activity or metabolites can affect the host system directly or indirectly, so toxicity is not always directly related to the dose [36].

*Prebiotics*

Prebiotics contain molecules that can stimulate the growth and activity of commensal microorganisms. Prebiotics also increase the production of acetate, propionate, and butyrate which have anti-inflammatory effects, as well as increase the number of lymphocytes and leukocytes in intestinal lymphoid tissue, and increase intestinal IgA secretion [37]. Evidence for the effectiveness of prebiotics as a therapy for AD is still limited. A randomized double-blind placebo study of 134 infants with a history of atopy in parents showed that the incidence of AD at the age of 2 years was higher in the group given regular formula without prebiotics compared to the intervention group given formula with a mixture of prebiotics for 6 months after birth [38].

*Synbiotics*

Synbiotics are synergistic interactions between probiotics and prebiotics that have a positive impact on skin and intestinal conditions. Synbiotics affect the development of commensal intestinal microflora by stimulating the growth of probiotics with prebiotics so that they can inhibit the growth of pathogenic microflora in the intestine. Synbiotics reduce the concentration of toxic metabolites in the body such as nitrosamine superoxide and some carcinogenic substances, and prevent the process of putrefaction in the intestine. Studies in mice fed with inulin, oligofructose, *Lactobacillus rhamnosus*, and *Bifidobacterium lactis* showed higher levels of intestinal IgA. Synbiotics also reduced levels of pathogenic microflora, promoted the development of commensal bacteria, and increased the absorption of calcium, magnesium, and phosphorus [39]. A meta-analysis study consisting of 6 RCTs (n=369) showed a decrease in the SCORAD index after receiving synbiotics for 8 weeks. Subgroup analysis showed that the beneficial effects were only significant when using mixed bacterial strains and when used in children aged 1 year or older [40].

## CONCLUSION

Based on the literature available to date, it is strongly suggested that the composition and ratio of the gut microbiome are associated with increased production of neurotransmitters and neuromodulators. These active substances may further influence the clinical course of AD affect the skin barrier (structure and function) and have important implications for aspects of immune system regulation. To date, the overall research evidence emphasizes the importance of the role of the skin and also the gut microbiota in the etiopathogenesis and severity of AD. Supplementation with specific probiotic strains does not always result in significant changes in the entire gut and skin microbiome. Therefore, promoting breastfeeding, encouraging vitamin D supplementation in pregnant women and infants, and limiting the use of antibiotics early in life may reduce the risk of AD. Soon, drugs and supplements containing personalized microbial strains may also play an important role in the treatment of AD.

## REFERENCES

[1] Chu DK, Koplin JJ, Ahmed T, Islam N, Chang CL, Lowe AJ. How to Prevent Atopic Dermatitis (Eczema) in 2024: Theory and Evidence. J Allergy Clin Immunol Pract. 2024;12(7):1695-1704. doi:10.1016/j.jaip.2024.04.048

[2] Kim J, Kim BE, Leung DYM. Pathophysiology of atopic dermatitis: Clinical implications. Allergy Asthma Proc. 2019;40(2):84-92. doi:10.2500/aap.2019.40.4202

[3] Mashiko S, Mehta H, Bissonnette R, Sarfati M. Increased frequencies of basophils, type 2 innate lymphoid cells and Th2 cells in skin of patients with atopic dermatitis but not psoriasis. J Dermatol Sci. 2017;88(2):167-174. doi:10.1016/j.jdermsci.2017.07.003

[4] Su C, Yang T, Wu Z, Zhong J, Huang Y, Huang T, Zheng E. Differentiation of T-helper cells in distinct phases of atopic dermatitis involves Th1/Th2 and Th17/Treg. Eur. J. Inflamm. 2017;15(1):46-52. DOI: 10.1177/1721727X17703271

[5] Rehbinder EM, Advocaat Endre KM, Lødrup Carlsen KC, et al. Predicting Skin Barrier Dysfunction and Atopic Dermatitis in Early Infancy. J Allergy Clin Immunol Pract. 2020;8(2):664-673.e5. doi:10.1016/j.jaip.2019.09.014

[6] Simpson EL,Leung Donald Y.M, Eichenfield LF, Boguniewicz, "Atopic Dermatitis" Fitzpatrick's Dermatology 9th edition. McGrawHill Education, 2019, 356.

[7] Schneider L, Hanifin J, Boguniewicz M, et al. Study of the Atopic March: Development of Atopic Comorbidities. Pediatr Dermatol. 2016;33(4):388-398. doi:10.1111/pde.12867
[8] Williamson S, Merritt J, De Benedetto A. Atopic dermatitis in the elderly: a review of clinical and pathophysiological hallmarks. Br J Dermatol. 2020;182(1):47-54. doi:10.1111/bjd.17896
[9] Geoghegan, J.A., Irvine, A.D., Foster, T.J. 2018. Staphylococcus aureus and Atopic Dermatitis: A Complex and Evolving Relationship. Trends in Microbiology; 26:484–497.
[10] Braun, C., Patra, V., Lina, G. et al. The role of skin dysbiosis in atopic dermatitis. Eur J Dermatol 32, 439–444 (2022). https://doi.org/10.1684/ejd.2022.4289
[11] Demessant-Flavigny AL, Connétable S, Kerob D, Moreau M, Aguilar L, Wollenberg A. Skin microbiome dysbiosis and the role of Staphylococcus aureus in atopic dermatitis in adults and children: A narrative review. J Eur Acad Dermatol Venereol. 2023;37 Suppl 5:3-17. doi:10.1111/jdv.19125
[12] Yamazaki Y, Nakamura Y, Núñez G. Role of the microbiota in skin immunity and atopic dermatitis. Allergol Int. 2017;66(4):539-544. doi:10.1016/j.alit.2017.08.004
[13] Fyhrquist N, Muirhead G, Prast-Nielsen S, et al. Microbe-host interplay in atopic dermatitis and psoriasis. Nat Commun. 2019;10(1):4703. Published 2019 Oct 16. doi:10.1038/s41467-019-12253-y
[14] Reiger M, Schwierzeck V, Traidl-Hoffmann C. Atopisches Ekzem und Mikrobiom [Atopic eczema and microbiome]. Hautarzt. 2019;70(6):407-415. doi:10.1007/s00105-019-4424-6
[15] Hrestak D, Matijašić M, Čipčić Paljetak H, Ledić Drvar D, Ljubojević Hadžavdić S, Perić M. Skin Microbiota in Atopic Dermatitis. Int J Mol Sci. 2022;23(7):3503. Published 2022 Mar 23. doi:10.3390/ijms23073503
[16] Seite S, Flores GE, Henley JB, et al. Microbiome of affected and unaffected skin of patients with atopic dermatitis before and after emollient treatment. J Drugs Dermatol. 2014;13(11):1365-1372.
[17] Ellis JR, Powell EJ, Tomasovic LM, Marcheskie RL, Girish V, Warman A, Sivaloganathan D. Changes in the Skin Microbiome Following Dermatological Procedures: A Scoping Review. Appl. Microbiol. 2024; 4(2):972-985. https://doi.org/10.3390/applmicrobiol4020066
[18] Bäckhed F, Roswall J, Peng Y, et al. Dynamics and Stabilization of the Human Gut Microbiome during the First Year of Life [published correction appears in Cell Host Microbe. 2015 Jun 10;17(6):852. Jun, Wang [corrected to Wang, Jun]] [published correction appears in Cell Host Microbe. 2015 Jun 10;17(6):852. doi: 10.1016/j.chom.2015.05.012]. Cell Host Microbe. 2015;17(5):690-703. doi:10.1016/j.chom.2015.04.004
[19] Lee SY, Lee E, Park YM, Hong SJ. Microbiome in the Gut-Skin Axis in Atopic Dermatitis. Allergy Asthma Immunol Res. 2018;10(4):354-362. doi:10.4168/aair.2018.10.4.354
[20] Fujimura KE, Sitarik AR, Havstad S, et al. Neonatal gut microbiota associates with childhood multisensitized atopy and T cell differentiation. Nat Med. 2016;22(10):1187-1191. doi:10.1038/nm.4176
[21] Salem I, Ramser A, Isham N, Ghannoum MA. The Gut Microbiome as a Major Regulator of the Gut-Skin Axis. Front Microbiol. 2018;9:1459. Published 2018 Jul 10. doi:10.3389/fmicb.2018.01459
[22] Mahmud MR, Akter S, Tamanna SK, et al. Impact of gut microbiome on skin health: gut-skin axis observed through the lenses of therapeutics and skin diseases. Gut Microbes. 2022;14(1):2096995. doi:10.1080/19490976.2022.2096995
[23] Gagliardi A, Totino V, Cacciotti F, et al. Rebuilding the Gut Microbiota Ecosystem. Int J Environ Res Public Health. 2018;15(8):1679. Published 2018 Aug 7. doi:10.3390/ijerph15081679
[24] Wollenberg A, Barbarot S, Bieber T, et al. Consensus-based European guidelines for treatment of atopic eczema (atopic dermatitis) in adults and children: part I [published correction appears in J Eur Acad Dermatol Venereol. 2019 Jul;33(7):1436. doi: 10.1111/jdv.15719]. J Eur Acad Dermatol Venereol. 2018;32(5):657-682. doi:10.1111/jdv.14891
[25] Luger T, Paller AS, Irvine AD, et al. Topical therapy of atopic dermatitis with a focus on pimecrolimus. J Eur Acad Dermatol Venereol. 2021;35(7):1505-1518. doi:10.1111/jdv.17272
[26] Kwon S, Choi JY, Shin JW, et al. Changes in Lesional and Non-lesional Skin Microbiome During Treatment of Atopic Dermatitis. Acta Derm Venereol. 2019;99(3):284-290. doi:10.2340/00015555-3089
[27] Bartnicka A, Szachta P, Gałecka M. Faecal microbiota transplant - prospects and safety. Pomeranian J Life Sci. 2015;61(3):282-286.
[28] Hill C, Guarner F, Reid G, et al. Expert consensus document. The International Scientific Association for Probiotics and Prebiotics consensus statement on the scope and appropriate use of the term probiotic. Nat Rev Gastroenterol Hepatol. 2014;11(8):506-514. doi:10.1038/nrgastro.2014.66
[29] Makrgeorgou A, Leonardi-Bee J, Bath-Hextall FJ, et al. Probiotics for treating eczema. Cochrane Database Syst Rev. 2018;11(11):CD006135. Published 2018 Nov 21. doi:10.1002/14651858.CD006135.pub3
[30] Fiocchi A, Pawankar R, Cuello-Garcia C, et al. World Allergy Organization-McMaster University Guidelines for Allergic Disease Prevention (GLAD-P): Probiotics. World Allergy Organ J. 2015;8(1):4. Published 2015 Jan 27. doi:10.1186/s40413-015-0055-2
[31] Cukrowska B, Ceregra A, Maciorkowska E, et al. The Effectiveness of Probiotic Lactobacillus rhamnosus and Lactobacillus casei Strains in Children with Atopic Dermatitis and Cow's Milk Protein Allergy: A Multicenter, Randomized, Double Blind, Placebo Controlled Study. Nutrients. 2021;13(4):1169. Published 2021 Apr 1. doi:10.3390/nu13041169
[32] Prakoeswa, C. R. S., L. Bonita, A. Karim, N. Herwanto, M. A. Umborowati, T. Setyaningrum, A. N. Hidayati, and I. S. Surono. 2020. "Beneficial Effect of Lactobacillus Plantarum IS-10506 Supplementation in Adults with Atopic Dermatitis: A Randomized Controlled Trial." Journal of Dermatological Treatment 33 (3): 1491–98. doi:10.1080/09546634.2020.1836310.

[33] Prakoeswa CRS, Herwanto N, Prameswari R, et al. Lactobacillus plantarum IS-10506 supplementation reduced SCORAD in children with atopic dermatitis. Benef Microbes. 2017;8(5):833-840. doi:10.3920/BM2017.0011

[34] Umborowati MA, Damayanti D, Anggraeni S, et al. The role of probiotics in the treatment of adult atopic dermatitis: a meta-analysis of randomized controlled trials. J Health Popul Nutr. 2022;41(1):37. Published 2022 Aug 17. doi:10.1186/s41043-022-00318-6

[35] Kim K, Lee E, Kim M, et al. Therapeutic effectiveness of probiotics for atopic dermatitis: A systematic review and meta-analysis of randomized controlled trials with subgroup analysis. Asian Pac J Allergy Immunol. Published online August 14, 2023. doi:10.12932/AP-280323-1576

[36] Cordaillat-Simmons M, Rouanet A, Pot B. Live biotherapeutic products: the importance of a defined regulatory framework. Exp Mol Med. 2020;52(9):1397-1406. doi:10.1038/s12276-020-0437-6

[37] Rusu E, Enache G, Cursaru R, et al. Prebiotics and probiotics in atopic dermatitis. Exp Ther Med. 2019;18(2):926-931. doi:10.3892/etm.2019.7678

[38] Grüber C, van Stuijvenberg M, Mosca F, et al. Reduced occurrence of early atopic dermatitis because of immunoactive prebiotics among low-atopy-risk infants. J Allergy Clin Immunol. 2010;126(4):791-797. doi:10.1016/j.jaci.2010.07.022

[39] Pérez-Conesa, D., López, G., Abellán, P., Ros, G. Bioavailability of calcium, magnesium and phosphorus in rats fed probiotic, prebiotic and synbiotic powder follow-up infant formulas and their effect on physiological and nutritional parameters. J. Sci. Food Agric. 2006; 86:2327–2336.

[40] Chang YS, Trivedi MK, Jha A, Lin YF, Dimaano L, García-Romero MT. Synbiotics for Prevention and Treatment of Atopic Dermatitis: A Meta-analysis of Randomized Clinical Trials [published correction appears in JAMA Pediatr. 2016 Mar;170(3):299]. JAMA Pediatr. 2016;170(3):236-242. doi:10.1001/jamapediatrics.2015.3943