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SCALP MICROBIOME IN ALOPECIA: A NEW DIRECTION IN TRICHOLOGICAL DIAGNOSTICS AND FOLLICLE RESTORATION

Abstract

The theoretical issues of the formation of the epidermal barrier of the skin (with the participation of keratinocytes and individual non-keratinocytes of the epidermis), the participation of skin appendages (sebaceous glands and sweat glands) in its formation are investigated. The main points of the coexistence of skin components and the most numerous representatives of the skin microbiome, which form the basis of the dynamic equilibrium inherent in the concept of "healthy skin", are considered. The main pathogenetic mechanisms in the development of skin diseases, including scalp diseases and the causes of hair loss, associated or not associated with changes in the skin microbiota, are highlighted. Certain existing and certain possible ways and methods of correcting pathological skin conditions, including scalp diseases, accompanied by alopecia, are highlighted. Promising directions for further research and development of the possibilities of using topical correction of the microbiota using probiotics and their introduction into clinical practice and the practice of salon procedures are outlined.

Keywords

microbiota, alopecia, hair follicle, postbiotics, probiotics

Problem statement

It is known that skin health, as a complex concept, depends on many factors and is determined by the appearance, morphological state of its main components

and derivatives, pH level, degree of hydration, color, and not only the absence of pathological visible changes. To ensure skin health, it is important to maintain a balance in the ratio of morphological structures and microbiota, as a key factor in maintaining its homeostasis, as evidenced by studies in recent years (De Almeida, Antiga & Lulli, 2023). It has been proven that Microorganisms of human skin are able to protect it from pathogens, control inflammation and modulate adaptive immune pathways. As much as the saprophytic microbiota is important for metabolic balance and protection of the skin from pathogenic factors, it is also demanding of the environment provided by skin cells, intercellular components and substances-products of glandular secretion. Imbalance of the skin microbiota can lead to such pathologies as psoriasis, eczema, atopic dermatitis, alopecia of various genesis and others. In addition to a cosmetic defect, skin pathologies acquired as a result of skin dysbiosis carry a threat of developing concomitant pathologies, triggering chain reactions and playing the role of certain markers that can warn about the probable development of internal pathology. Dysbiotic skin pathologies exist on the verge of a collision between the spheres of influence of various specialists in the field of medicine and the beauty industry, forcing trichologists to delve deeper into the problem of the outer skin, involving scientists in consultation to develop a joint strategy of action.

The purpose of the work is to analyze modern research on the scalp microbiome and the possibility of its normalization in the work of a trichologist.

Presentation o f the main material o f the study

Since the object of professional activity of a trichologist is the scalp with its derivatives, it is necessary to know well the morphology of the main components of healthy skin in order to clearly understand what ensures the composition of the environment for the normal existence of microbiota, so that in case of disturbances, the balance can be modeled by influencing the main active components. The skin is the largest organ of the human body, which has its own

structure, blood supply, innervation and is endowed with certain basic and additional functions. The main functions of the skin include: providing protection (mechanical, chemical, thermal), regulating body temperature, storing blood, sensory function (perceiving various types of sensations through receptors (temperature, pain, touch), excretory (removal of decay products, bile acids from the body), immune (due to the functioning, migration and differentiation of immune cells in it), respiratory (Lutsyk & Chaikovskyi, 2018). The condition of the skin reflects the functional state of the body and especially such of its systems as digestive, endocrine, immune, urinary, reproductive, cardiovascular. An experienced doctor can establish a diagnosis based on the condition and color of the skin. Of the additional functions, I would like to highlight the cosmetic function, since the statement that "beautiful skin is healthy skin" is undeniable. It is only worth adding: if a person's skin is imperfect for some reason, then this is not a sentence, not forever, because there is a beauty industry that has a powerful arsenal of various means and methods for correcting cosmetic defects of the skin and hair, and which has long been using the achievements of scientists and even directing them in research directions according to current requests.

The scalp is constructed on the same principle as the skin of other parts of the body, but differs in a greater thickness of the dermis, hypodermis, the number of hairs and sebaceous and sweat glands (Lutsyk & Chaikovskyi, 2020). The skin of the scalp, face, hands is in the greatest contact with the environment, therefore it is more populated by various microorganisms and fungi than other areas hidden by clothing. The influence of external factors on the scalp, not only bacterial, but also physical, can change the microbiota, which will act as a catalyzing factor in the pathogenesis of skin diseases. Normally, between the mature keratinocytes of the middle rows of the stratum corneum of the epidermis, an extracellular layer of lipids is located, which participates in the formation of the epidermal water barrier, making the epidermis impermeable to water and substances dissolved in it (in both

directions) and various microorganisms and fungi. The skin barrier, formed by dense layers of horny scales, bonded with lipid "glue", covered with a layer of a complex compound of sebaceous and sweat gland secretions, supplemented by biofilm components, is quite strong and poorly permeable (Shah et al., 2024). Large molecular structures cannot usually pass through it. There is a hypothesis that dermal macrophages accumulated in the locations of hair follicles can increase the permeability of the skin. However, there are formations in the epidermis that can serve as entrance gates through which pathogens can bypass the natural barrier: the outlets of the excretory ducts of the skin sweat glands, hair follicles. The hair follicle is the final section of the hair-sebaceous canal, starting from the isthmus (the narrowed part of the canal that extends from the attachment site of the levator pilonidal muscle), where the excretory duct of the skin sebaceous gland opens, secreting the secret. In the skin of those areas covered with hair, complexes of structures called hair-sebaceous units are distinguished. They include: hair follicle, hair shaft, levator muscle of hair and sebaceous gland. There are more such units in the scalp than in other areas of the body (Pavlina & Ross, 2021). The activity of the sebaceous glands is controlled by sex hormones. High levels of androgens during puberty lead to hyperproduction of sebum, which is clinically manifested by the appearance of comedones and rapid greasiness of the hair. The product of sebocyte cells, highly differentiated exocrinocytes of the sebaceous glands, is a waxy oily substance (sebum), which they secrete in a holocrine manner. Sebum, which is excreted into the lumen of the funnel, is a mixture of triglycerides, diglycerides and free fatty acids, wax esters, squalene, cholesterol and its esters. According to scientific research, the composition of the sebaceous gland secretion includes: antioxidants, some anti-inflammatory and pro-inflammatory substances and antimicrobial peptides. Human sebum, under conditions of constant body temperature and skin pH below 5, is a unique chemical composition for each organism and a dynamic complex. The chemical

composition of human sebum can change according to the functional state of organs and systems, quality of nutrition, use of drugs, hormonal status and a number of external factors, which include microorganisms and fungi. In cases of reduced bactericidal activity of sebum, it can become a breeding ground for the reproduction of pathogenic microorganisms. Normally, sebum covers the surface of the hair shaft and the surface of the epidermis, mixing with other components that migrated from the outside or were produced by sweat glands and keratinocytes of the epidermis.

Merocrine sweat glands are located in all areas of the body where there is skin, except for the transition zone of the lips and external genitals. They are very abundant in the scalp. The secret of merocrine glands is called sweat and consists of water, sodium chloride, urea, uric acid, ammonia and contains proteins in low concentrations. The main function of merocrine glands is to regulate body temperature by evaporating water from sweat on the surface of the epidermis and cooling it. Under certain conditions (impaired function of the urinary system, gastrointestinal system, bile secretion), merocrine sweat glands can work as an excretory organ, actively removing additional components to be utilized to the surface of the epidermis, thereby changing the pH, skin temperature, chemical composition of the environment. In some pathologies of internal organs, the above-described changes lead to the appearance of a skin component among the clinical signs of the disease, in the form of a change in skin color, the appearance of areas of irritation, inflammation, alopecia, and peeling. Apocrine sweat glands are located in the following places: armpit, areola and nipples of the mammary glands, skin of the perianal area and external genitalia. The secret of the apocrine glands consists of water, proteins, carbohydrates, ammonia, lipids and organic compounds, which acquire a specific individual odor after being released onto the surface of the epidermis and upon contact with bacterial flora.

Thus, the secretion of the sebaceous glands, sweat glands, and the secretion products of keratinocytes of the hair follicle, mixing in the funnel, are removed as a complex to the surface of the epidermis, creating a certain environment for microorganisms and saprophytic fungi.

Microbiota is considered to be a collection of microorganisms, fungi and viruses that occur in the environment of a person's habitat and in one way or another come into contact with it, living on the surface of the body or inside. The colonization of the human body by representatives of the microbiota begins immediately after birth and continues throughout life. The colonization process is dynamic, depends on many factors, including the health status of the macroorganism, which ensures the individual composition of the microbiota in each person. However, the most dominant species of microbiota in human skin are *Cutibacterium, Corynebacterium* and *Staphylococcus* (De Almeida, Antiga & Lulli, 2023). It is noteworthy that the first of them prefers areas enriched with sebaceous glands, and the last two - with sweat glands.

Among the skin saprophytes that form biofilm communities that, in a certain way, through competitive displacement, counteract the reproduction of pathological flora and fungi on the scalp, the following are distinguished: *Staphylococcus epidermidis* (*S. epidermidis*), which forms a biofilm between the upper layers of the stratum corneum of the epidermis, mainly in normal dry skin*;* *Cutibacterium acne* (*C. acnes)* which penetrates deep into the hair follicle to the sebaceous gland and prefers oily skin (Polak-Witka et al., 2020).

It is known that not only representatives of the microbiota choose the host, stimulating the functions of keratinocytes and non-keratinocytes of the skin, but also the cells of the host itself carry out selective filtration of representatives of the microbiota, recognizing some of them as saprophytes and others as pathogens, by secreting antimicrobial peptides (AMPs) of a wide spectrum of activity. Some AMPs are produced on a constant basis, being an integral component in the

secretory menu, and others - under the catalytic influence of representatives of the microbiota, such as *Cutibacterium*. In addition, some microorganisms *(S. epidermidis* and *S. Hominis)* are capable of producing certain substances with antibacterial effects to inhibit the reproduction of pathogenic representatives of the microflora *(S. aureus)*. The most common saprophytic bacteria of the scalp that have been found in swabs taken from healthy skin are *Cutibacterium* spp. (successfully persists in the environment of sebaceous gland secretion, hydrolyzes triglycerides and releases free fatty acids, thanks to which it is firmly fixed to the epidermis) and *Staphylococcus* spp. (with a predominance *S. epidermidis), which account for approximately 90%* (Shibagaki et al., 2017). *Qualitative changes in the scalp microbiota can be prognostic indicators, as they are closely* related to changes in the body as a whole. As for fungi, the most common species found in the epidermis of healthy scalps were: *Malassezia*, *Malassezia globose* (*M. globosa)* and *M. Restricta* (Xu et al., 2016).

It should be noted that normally the scalp is not only colonized by bacteria and fungi. Saprophyticity is inherent in some mites, for example: *Demodex folliculorum* is usually found in the hair follicles, while *Demodex short* - in the sebaceous glands.

Any processes occurring in the scalp necessarily affect the condition and function of its derivatives, such as hair and glands. It is important that the secretion of the glands is a component of the scalp microbiota environment, and hair is an indicator of the condition of the skin and a source of regeneration, if we talk about the hair follicle. Alopecia is an external manifestation of excessive hair loss on the head. Alopecias come in various types and genesis. They can be a manifestation of a skin disease, or primary alopecias. The list of causes of alopecia is replenished with new items every year so rapidly that the concerned medical community is taking this to the international level of discussion, as, for example, the post-COVID consequences of skin diseases (Andriyiv et al., 2021).

When comparing the skin microbiota of people with healthy skin and those with alopecia areata, dysbiosis was found. Among the changes that were particularly significant were: increased levels of Actinobacteria in milder cases of the disease and high levels of gram-negative bacteria (Alistipes inops and Bacteroides pleibeius) in severe forms of alopecia (Gomez-Arias et al., 2024). Despite the correlation of the severity of the disease with the quality of the microbiota, it is difficult to say with certainty that it is the changes in the microbiome that led to alopecia, since other pro-inflammatory factors have been identified, such as high levels of cytokines locally and high levels of immunoglobulins in the blood. However, the causal significance of dysbiosis of the skin microbiome in the pathogenesis of seborrheic dermatitis of the scalp has been proven precisely (Lin et al., 2021). As a result of a study conducted on patients with healthy scalp and skin affected by seborrheic dermatitis, the difference was reliably proven precisely between the fungal and bacterial microbiota, and not skin pH, sebum secretion or skin hydration level. Potential fungal biomarkers of seborrheic dermatitis were Malassezia and Aspergillus, and bacterial - Staphylococcus and Pseudomonas. The cascade of release of biologically active substances induced by the above-described microorganisms and fungi, as catalysts in the pathogenesis of seborrheic dermatitis, entailed reactive migration of macrophages, histiocytes and other immunocytes into the affected area of the scalp with subsequent hyperproliferation of the epidermis and dermis, perivascular edema, decreased capillary blood flow, impaired blood supply to the skin and hair follicles, increased hair loss, and alopecia. Given the initiating role of certain types of fungi and bacteria in the occurrence of seborrheic dermatitis of the skin, it was logical to conduct a study using shampoos with the addition of antifungal and antibacterial agents. This study proved the effectiveness of adding targeted cosmetics to the treatment regimen for seborrheic dermatitis of the scalp (Maître et al., 2025).

Decalvant folliculitis, a type of primary alopecia with unclear pathogenesis, is associated with the detection of large numbers of *S. aureus colonies*. The occurrence of androgenetic alopecia is associated with a high concentration of macrophages and lymphocytes in the scalp, as a result of mycoinflammation in the upper layers of the stratum corneum of the epidermis, which arose due to changes in the composition of the microbiota in an environment distorted by hyperproduction of sebum. A bacterial factor is also not excluded, since the use of antibacterial drugs in the composition of cosmetics has given a positive result.

It has been discovered that a common genetically determined skin disease, psoriasis, can be induced by external factors such as medications , microorganisms, and stress (Gomez-Moyano et al., 2014). Scalp swabs from psoriasis patients have been found to contain large numbers of colonies *of M. globosa*, *M. furfur, and* and positive cultures of species *Malassezia*. The combination of scalp dysbiosis in psoriasis patients with intestinal dysbiosis turned out to be interesting (Bury, 2018).

Recently, special attention has been paid to restoring the skin ecosystem through the use of certain probiotics as one of the main points of the treatment protocol for certain skin diseases and alopecia (Sweeney & Kalan, 2021).

It is known that between the epidermis of the skin and the complex of epidermis derivatives, which, like it, are dynamic and secretory active structures, there is a morpho-functional balance, which in combination with representatives of the biofilm supports a conditionally healthy state of the skin. Any shift in organic, chemical, physiological and other indicators in one direction or another can catalyze a cascade reaction of changes in the condition and composition of the skin, which, moving from temporary to permanent status, in the absence of timely correction, increase the risk of cosmetic defects, transferring the problem from the purely medical to the social sphere. Considering that the pathogenesis of most types of skin and hair lesions contains a microbiome component, the use of

species-specific drugs in the composition of medical and cosmetic products is logical, but this should not be the method of choice, but only one of the points of the treatment protocol. It is urgent to find ways to transport antibacterial and antifungal substances through the dense epidermal barrier, using not only traditional, but also developing new methods and means of transdermal delivery. However, since the microbiota is a key point in the preservation and maintenance of the epithelial barrier of the skin, the use of antibacterial drugs in scalp care products is not always justified, as it carries the risk of dysbiosis with subsequent critical changes in the skin and hair, such as skin infections and inflammatory diseases. The effectiveness of topical probiotics for the correction of intestinal dysbiosis in the treatment of skin diseases such as atopic dermatitis, acne and rosacea has been proven (Knaxtedt, Knaxtedt & Guterrait, 2020). Recently, the method of combined use of oral and local probiotics for the complex treatment of skin diseases associated with microbiota disorders has been of particular interest (Tamer & Kekilli, 2024). In a study conducted on patients with skin diseases associated with microbiota disorders, probiotics were applied to the affected areas of the skin. The results showed positive changes among the sample participants, which may be extremely promising in terms of further research and development of protocols for the external use of probiotics in the treatment of dysbiotic skin conditions and dysbiotic alopecia (Lee, 2019). The positive effect of properly selected professional skin care products on the growth of strains has been proven *Cutibacterium* and *Staphylococcus*, which can maintain microbial balance by inhibiting the growth of pathogenic flora (Hwang et al, 2021) and stimulating keratinocytes and sebocytes to produce natural components. In connection with the study of the skin microbiota, scientists in recent years have insisted on maintaining a comfortable environment for them (pH below 5). It has been proven that cosmetics that increase the pH to alkaline can cause skin dysbiosis and various manifestations of organic disorders of the epidermis, from peeling to

ulcers (Bouslimani et al, 2019). Some cosmetic companies, taking into account the opinion of scientists, began to produce lines of cosmetic products for skin with a weakly acidic pH. Cooperation between scientists and manufacturers of cosmetic products, as shown by reviews of recent years, is extremely effective and promising in terms of improving protocols for correcting various pathological conditions of the skin and hair and the development of the companies themselves due to the growing demand for products. The use of probiotics is scientifically justified not only for correcting the microbiota of the gastrointestinal tract, genitals, but also of various areas of the skin. Skin probiotics were first successfully used to treat acne and seborrhea in 1912. Since then , interest in their use has increased, as new information has emerged. The properties of some microorganisms have been successfully studied and introduced into cosmetology*:* C. a cnes - *antibacterial microflora that inhibits the growth of pathogens;* L. Plantarum - in addition to its antibacterial function , it has the function of blocking sebocytes, which is used in the treatment of acne; Streptococcus thermophiles – stimulate the production of ceramides when applied to the skin, thereby increasing its moisture and stabilizing the natural barrier; topical application of the L. Acidophilus strain is able to protect the skin from photodamage by inducing and activating antioxidant processes; topical application of Nitrosomonas eutropha accelerated wound healing by stimulating regenerative processes and collagen production (De Almeida, Antiga & Lulli, 2023). The complex use of probiotics adsorbed on peptides and nanoparticles to increase bioavailability and improve antibacterial effect against pathogens turned out to be extremely effective. Peptides as an independent antibacterial agent turned out to be very effective, especially in the treatment of purulent wounds (Öhnstedt et al, 2023). When studying the effect of using peptides for regeneration, scientists discovered their additional therapeutic possibilities, in particular: increased angiogenesis, collagen

formation, and cell proliferation (Yang et al., 2023), which allowed them to be used in regenerative trichology and cosmetology.

Skin and oral health specialists have received active positive feedback on the use of postbiotics (paraprobiotics or inactivated probiotics), which are essentially the remains of dead representatives of the microbiota and their secretion products (Nataraj, Ali, Bekhare & Yadav, 2020). The positive effect of their use, in addition to direct biological action, has been implicated in the activation of the host's immune system. Unlike probiotics, postbiotics cannot form colonies, so they can be used in patients with weak immunity without the risk of generalization of active colony-forming microorganisms. To solve various skin problems, so-called homogenates or lysates of non-living microorganisms strains are used.

Conclusions

The skin microbiota is an important target for a diverse corrective effect aimed at improving the condition of the skin and its derivatives, taking into account the needs at the time of the study. It is important that both the condition of the skin (morphological, physical, functional, biochemical) can change rapidly under the influence of external and internal factors, and the composition of the microbiota and the need for its individual representatives can change dynamically and radically. Therefore, the composition and significance of the skin microbiota, the conditions for its harmonious coexistence with the host organism are an inexhaustible source of new information for further research by scientists and promising developments of human skin care products, the implementation of which in practice will fall on the shoulders of cosmetologists and trichologists.

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