Scientific Research Publishing

Journal of Biosciences and Medicines, 2026, 14(3), 566-584
https://www.scirp.org/journal/jbm
ISSN Online: 2327-509X
ISSN Print: 2327-5081

Pathophysiology of Androgenetic Alopecia and Implications for Treatment: An Overview of Current Literature

Neha Iska[1], Esther Nwozo[2], Hafsa Hassan[3], Navya Peddireddy[4], Alejandra Sataray-Rodriguez[5], Kelly Frasier[6*]

[1]School of Medicine, Wayne State University, Detroit, MI, USA
[2]The Lewis Katz School of Medicine at Temple University, Philadelphia, PA, USA
[3]College of Medicine, Northeast Ohio Medical University, Rootstown, OH, USA
[4]Texas College of Osteopathic Medicine, University of North Texas Health Science Center, Fort Worth, TX, USA
[5]Reno School of Medicine, University of Nevada-Reno, Reno, NV, USA
[6]Department of Dermatology, Northwell Health, New Hyde, NY, USA
Email: *kellymariefrasier@gmail.com

How to cite this paper: Iska, N., Nwozo, E., Hassan, H., Peddireddy, N., Sataray-Rodriguez, A. and Frasier, K. (2026) Pathophysiology of Androgenetic Alopecia and Implications for Treatment: An Overview of Current Literature. *Journal of Biosciences and Medicines*, **14**, 566-584.
https://doi.org/10.4236/jbm.2026.143042

Received: August 7, 2025
Accepted: March 24, 2026
Published: March 27, 2026

Abstract

Androgenetic alopecia (AGA) is the most common form of hair loss, affecting both men and women through a progressive follicular miniaturization. While historically considered a non-inflammatory and cosmetic condition, growing evidence reveals a multifactorial pathogenesis involving genetic predisposition, hormonal dysregulation, sebaceous gland alterations, lipidomic changes, and localized inflammation. Androgens, particularly dihydrotestosterone (DHT), play a central role in AGA by inducing follicular miniaturization, promoting perifollicular fibrosis, and altering sebaceous gland structure and function. Genetic variants, including polymorphisms in the androgen receptor (AR) gene, influence individual susceptibility and therapeutic response. Additionally, disruptions in lipid metabolism and immune privilege contribute to the inflammatory microenvironment and follicular degeneration observed in AGA-affected scalps. Current management strategies include topical minoxidil, 5α-reductase inhibitors like finasteride and dutasteride, and adjunctive therapies targeting inflammation and seborrheic conditions. Emerging treatments, however, offer regenerative potential by restoring follicular cycling, improving vascularization, and modulating inflammatory pathways. This review synthesizes current understanding of AGA pathophysiology and explores evolving treatment modalities aimed at halting disease progression, improving hair density, and restoring scalp homeostasis. By addressing the condition as both a dermatologic and systemic phenomenon, future therapies may expand beyond cosmetic outcomes to more holistic and personalized care approaches.

Keywords

Androgenetic Alopecia, Hair Follicle Miniaturization, Dihydrotestosterone, Androgen Receptor, Sebaceous Glands, Inflammation, Platelet-Rich Plasma, Stem Cell Therapy

1. Introduction

AGA is a form of non-inflammatory, non-scarring alopecia that impacts both men and women [1]. AGA is the most common form of hair loss in men affecting nearly 50% of men before the age of 50, and also 40% of women by the age of 70 [2] [3]. AGA is characterized by a gradual and distinct patterned hair loss, with a variable presentation dependent on sex [4] [5]. In men, AGA preferentially affects the temples, vertex and mid frontal scalp [4]. In women, the anterior hairline is preserved and thinning occurs primarily at the crown and along the part line [4]. Nonetheless, while AGA progresses in both men and women, for men AGA can produce complete baldness, whereas total baldness in any area is rare for women [5].

AGA morbidity is primarily psychological, with some concerns regarding reduced protection from environmental stressors. Notably, AGA correlates with a slightly increased risk of squamous cell carcinoma (SCC), basal cell carcinoma (BCC), and melanoma of the head and neck [6]. Furthermore, since hair serves as an essential component of an individual's self-image, AGA can have a significant impact on self-perception in those diagnosed. While many individuals with AGA cope well, those with the most extensive hair loss, early onset, and with the strong belief that their balding is progressive, are among the most distressed [7].

Given the prevalence and impact of AGA, considerable efforts are underway to outline the pathophysiology behind the disease. As an overview, for both sexes, hair follicle miniaturization remains the histological hallmark of AGA, characterized by shrunken dermal papillae, structures located at the follicular base that are directly related to the size of the corresponding hair shafts produced [8]. Ultimately, hair loss in AGA is multifactorial, but involves the replacement of large terminal follicles by small vellus hairs [9] [10]. While the true pathogenesis of AGA remains obscure, this paper aims to explore the etiology thought to underlie AGA, including genetic, hormonal, and pathophysiological mechanisms including the miniaturization of hair follicles, sebaceous gland overpopulation, amongst other changes. Furthermore, considering the landscape of variably effective treatment, we also hope to overview current solutions and subsequently propose new areas for innovation.

2. Genetic Influences

AGA is highly heritable and exhibits polygenic inheritance. Twin studies have identified heredity as accounting for nearly 80% of the predisposition to baldness [11] [12]. Genetic factors modify the magnitude and character of hair follicle response to

circulating androgens. Since baldness risk increases with the number of affected family members, AGA inheritance is also speculated to be polygenic [13] [14]. Genome-wide association studies have identified various risk loci, including genes involved in encoding the AR and those that regulate non andro-gen-dependent pathways, including the Wnt-B-catenin and Notch signalling pathways [15] [16].

Advances in genetic testing also have applications for AGA. One gene polymorphism-based diagnostic test has the ability to predict the chances of future AGA with considerable accuracy [14] [17]. This screening test works by reporting the presence of an X-chromosome located AR gene variant implicated in determining the hair follicle's response to DHT, a highly potent androgen intimately involved in AGA pathogenesis [14] [17]. Knowing an individual's predisposition is particularly important considering that early intervention achieves the most desirable outcomes in AGA [18]. Furthermore, another gene test has been developed to characterize individual response to finasteride therapy [19]. This test measures CAG repeat length on the AR gene, and individuals with a shorter repeat length experience greater therapeutic effects in response to finasteride treatment [19].

3. Hormonal Influences

Androgens, such as testosterone and DHT, are critical regulators of human hair follicle growth. Furthermore, their actions differ by body site, a phenomenon referred to as the "androgen paradox" [20]. While androgens stimulate hair growth in areas like the beard and axillae, they induce hair follicle miniaturization on the scalp in AGA [20]. Androgens play an essential role in AGA by interacting with ARs expressed in hair follicle dermal papilla cells [21].

The development of AGA is driven by increased local androgen metabolism, rather than systemic hormone levels. In AGA, men typically have normal circulating testosterone levels but demonstrate heightened local conversion of testosterone to DHT, via increased 5α-reductase activity, particularly in androgen-sensitive areas such as the vertex and frontal scalp [21] [22]. Elevated DHT binds to ARs in hair follicles' dermal papillary cells, leading to the gradual miniaturization of terminal hairs into vellus-like hairs, eventually leading scalp hair thinning [21]. Additionally, DHT promotes perifollicular fibrosis, an irreversible process closely related to hair follicle degradation [23]. AGA is also associated with reduced activity of the aromatase enzyme [24]. Aromatase is responsible for converting androgens into estrogens, the latter of which exhibit protective effects against follicular miniaturization [21]. Decreased aromatase expression in the scalp regions affected by AGA further contributes to the accumulation of active androgens in these areas, aggravating hair loss [21].

Sebaceous glands also play a role in the pathophysiology of AGA. Increased sebaceous gland activity, driven by androgens, leads to excessive sebum production, which may also contribute to microinflammation and oxidative stress in the follicular environment [24]. This inflammatory milieu accelerates follicular miniaturization and disrupts sebaceous gland function [24]. The inflammatory re-

sponse in AGA-affected scalp areas accelerates tissue remodeling, leading to an eventual reduction in follicular stem cell activity and contributes to the progressive nature of AGA [25]. Unique Cases Informing Hormonal AGA Pathogenesis

Observations from individuals with atypical hormonal profiles provide compelling evidence for the critical role of androgens in the pathogenesis of AGA. Eunuchoid patients, including prepubertal castrated men or individuals with congenital hypogonadism, typically do not develop AGA due to their lack of significant androgen exposure [23]. James Hamilton's seminal studies in the 1940s demonstrated that castrated males did not develop AGA unless they were administered exogenous testosterone, confirming the necessity of androgens in AGA development [21]. Moreover, these individuals exhibited significantly lower sebum production, reinforcing the relationship between androgens, sebaceous gland activity, and scalp conditions [24]. Similarly, individuals with type 2 5α-reductase deficiency exhibit a female-pattern distribution of axillary and pubic hair, little or no beard growth, and typically do not develop AGA, likely due to decreased DHT levels [20].

However, the true role of hormones in AGA is likely more nuanced. In Complete Androgen Insensitivity Syndrome (CAIS), mutations in the AR gene lead to the absence of functional ARs. Even though these individuals have normal or even increased circulating androgen levels, they typically do not develop AGA because the hair follicles cannot respond to androgen signaling [25]. Interestingly, while CAIS prevents the development of classic male pattern baldness, there are reports of some individuals with CAIS developing a pattern of hair thinning resembling female pattern hair loss (FPHL) [26]. The etiology of this phenomenon is still unclear, but its presence suggests that factors beyond androgen signaling. For example, genetic predisposition, microinflammation, or aberrant estrogen signaling could also contribute to hair loss in these cases [20]. One possibility is that cytochrome P450 enzymes aromatize androgens into oestrogens, which may inhibit hair growth by acting on the oestrogen receptor β expressed in human scalp hair follicles [27]. Nonetheless, consistent relationships between FPHL and androgen excess have yet to be established [27]. These insights broaden the therapeutic framework for AGA, suggesting that treatment strategies may extend beyond androgen-targeted approaches to also consider the roles of estrogenic signaling, genetic predisposition, and inflammation [20].

4. Pathophysiology

4.1. Hair Cycle in AGA

The hair growth cycle is a complex, tightly regulated process consisting of four primary phases, involving growth, transition, resting, and shedding, called anagen, catagen, telogen, and exogen, respectively [28]. The anagen phase is characterized by active cell proliferation within the hair bulb, leading to the production of the hair shaft [29]. In the scalp, the anagen phase typically lasts between two to eight years and determines the final length of the hair [29]. The catagen phase follows,

lasting approximately 2 to 3 weeks, during which hair growth ceases, and the hair follicle undergoes apoptosis-driven regression [30]. The telogen phase lasts about two to three months, involving resting of the old hair and simultaneous new hair development at the hair follicle base [31]. Lastly, the exogen phase describes the termination of telogen and initiation of anagen phase, of which new hair grows upward, pushing the old hair out and culminating in shedding [28].

In androgenetic alopecia (AGA), the normal hair cycle is disrupted, leading to progressive miniaturization of hair follicles and altered cycling dynamics. In AGA affected areas, increased AR density enhances DHT binding, resulting in the prolonged activation of androgen-responsive genes responsible for regulating hair follicle cycling [26]. Androgen-mediated signaling shortens the anagen phase while increasing the duration of the telogen phase, leading to progressive follicular miniaturization [32] [33]. Successive cycles result in the substitution of terminal hairs for thinner, less pigmented vellus hairs, *w*hich lack the robustness of healthy scalp hair [23]. The reduced duration of the anagen phase limits hair shaft elongation and contributes to the visible thinning characteristic of AGA.

4.2. Hair Follicle Miniaturization

Hair follicle miniaturization is the defining pathological feature of androgenetic alopecia (AGA), and involves the progressive reduction in hair follicle size, leading to the transformation of thick terminal hairs into fine, short vellus hairs [34]. This miniaturization process is largely driven by inflammatory and microenvironmental changes, but is best understood as a result of increased follicular sensitivity to DHT. DHT binds to ARs in the dermal papilla cells of the hair follicle, initiating signaling pathways that induce apoptosis of follicular cells and trigger the premature entry into the catagen phase [34]. The miniaturization process in AGA is often accompanied by DHT mediated perifollicular fibrosis, which creates a rigid extracellular matrix around the follicle, impairing its ability to regenerate and enter the anagen phase effectively [35]. This process results in shorter, thinner hair shafts and an overall reduction in hair density [35]. Over successive cycles, the eventually follicle's ability to regenerate diminishes, leading to baldness and thinning.

4.3. Glandular Changes

As mentioned previously, sebaceous glands are highly sensitive to androgens and play a significant role in the pathophysiology of AGA. These glands secrete sebum to lubricate the scalp and hair, helping to seal in moisture and prevent skin desiccation [36]. In AGA, sebaceous glands undergo morphological changes, exhibiting increased ductal branching and lobulations, or altered lipid metabolism [37]. Although sebaceous glands in miniaturized follicles may appear disproportionately enlarged, this phenomenon is not due to true glandular hypertrophy, but instead as a result of shrinkage of the surrounding hair follicle [33] [37].

In AGA-affected scalps there is increased binding affinity of sebaceous gland

cells for DHT, which leads to upregulated sebum production [37]. Excess sebum can create an occlusive environment around hair follicles, promoting microinflammation and oxidative stress, further accelerating follicular miniaturization [37]. Additionally, the sebaceous glands in AGA patients express significantly higher levels of ARs compared to non-AGA scalps, making them more responsive to circulating androgens [38]. Understanding the role of sebaceous gland alterations in AGA underscores the importance of addressing glandular changes. By targeting both the follicular and glandular components, clinicians can optimize treatment outcomes and improve scalp health in AGA patients.

4.4. Lipid Alterations

Lipidomics has allowed for novel ways to investigate AGA. There are significant changes in lipid content and metabolism in AGA, relative to healthy controls [39]. Variants of phosphatidylcholine (PC), the most biologically active phospholipid considered to possess regenerative and antioxidant effects, were noted to be significantly decreased in AGA [39] [40]. Autophagy plays a key role in initiating hair follicle activation and is initiated by phosphatidylethanolamine (PE), another phospholipid also found to be significantly decreased in AGA [37]-[41]. Amongst PE and PC, phosphatidylglycerol (PG) and phosphatidylinositol (PI), related to inflammatory response reduction and hair follicle regeneration respectively, were also significantly reduced in AGA patients [39] [42] [43]. Furthermore, triglyceride metabolites were found to be significantly increased in the scalp of male AGA patients, relative to female AGA patients, indicating the role sex may play in lipid metabolism [39]. Subsequently, lipidomics has considerable potential to identify key diagnostic biomarkers aiding in AGA diagnosis and characterization.

4.5. Inflammation Alterations

Although AGA. is typically classified as a non-inflammatory, non-scarring form of hair loss, histological evidence of inflammation has been reported. Mononuclear cells and lymphocytic infiltrates have been observed in nearly half of male AGA scalp samples [44]. Mast cell degranulation and fibroblast activation within hair follicle fibrous shifts has also been observed [44]. Moreover, T cell infiltrates are prominent in the region of the follicular bulge, a critical source of hair follicle stem cells [45]. Perifollicular infiltration of lymphocytes and mast cells, promote fibrosis and compromise follicle function, contributing to hair follicle miniaturization in AGA [44]. Critically, the hair bulge of human anagen hair follicles represents a site of relative immune privilege [46]. However, disruption of hair follicle immune privilege in AGA can be characterized by upregulation of MHC-1 and II expression, rendering hair follicles susceptible to inflammatory attack, and ultimately culminating in hair loss [46].

Macroscopic Patterns and Microscopic Progression in AGA

AGA follows a characteristic and progressive pattern of hair loss that macroscopically varies between males and females [2] [4]. Macroscopically, AGA typi-

cally begins at the frontal hairline, temples, and vertex of the scalp, gradually progressing to a receding hairline and thinning at the crown, which may eventually merge into larger bald areas [2]. In men, this is commonly classified using the Norwood-Hamilton scale, while the Ludwig scale is used for women, where diffuse thinning over the crown occurs while maintaining the frontal hairline [4].

Microscopically, AGA shows certain distinct alterations. Notably, AGA is characterized by miniaturization of hair follicles within scalp follicular units [34]. Terminal hair follicles progressively transform into finer, shorter vellus hairs, due to the effects of DHT and altered hair cycle dynamics [34]. This miniaturization results in a decrease in hair shaft diameter and length, leading to the clinical appearance of thinning hair [34]. Miniaturization is accompanied by a reduced number of terminal hairs within each follicular unit, with affected areas showing a higher proportion of vellus hairs compared to unaffected scalp regions [44]. In AGA, the follicular microenvironment also displays fibrotic changes, further contributing to disease progression. Increased extracellular matrix deposition and reduced vascularization in the scalp regions of AGA-affected individuals prevents nutrients from being delivered to hair follicles [23]. Over time, the accumulation of DHT-mediated perifollicular fibrosis and reduced vascularization further limits follicular regeneration, exacerbating hair loss [23].

5. Pharmaceutical Management

5.1. Topical Minoxidil

Topical minoxidil is amongst the most frequent therapies currently employed for AGA with proven efficacy, which works by enhancing blood supply in the scalp and thereby stimulating hair growth [47]. Minoxidil induces opening of potassium channels, thereby resulting in subsequent vasodilation and improved supply of oxygen and nutrition to miniaturized follicles [48]. This drug works by prolonging the growth phase of the hair cycle, which enables follicles to produce a thicker and healthier hair strand [48]. It is available in 2% and 5% formulation; effective in both men and women [33] [35]. Minoxidil is applied to the scalp, making this a rather convenient and noninvasive treatment; however, it needs to be used continuously to sustain any response [33]. The discontinuation of therapy generally results in resumption of miniaturization of hair follicles, highlighting the need for long-term compliance [33]. Most patients tolerate minoxidil well, though some develop scalp irritation, dryness, or even unwanted excessive hair growth on the face, which may be disturbing for some individuals [33].

5.2. Topical Antibiotics/Antifungals

Topical antibiotics and antifungals are not primary therapies for AGA, but do play an adjunctive role in the treatment of AGA, particularly in the presence of comorbid seborrheic dermatitis [49]. Antibiotics, such as clindamycin, are effective in reducing inflammation by targeting bacterial overgrowth that may contribute to localized irritation [47]. Ketoconazole, an antifungal, is an effective treatment for

seborrheic dermatitis produced by the yeast Malassezia [47]. Ketoconazole also inhibits the action of DHT on the scalp, thereby reducing sebum production [47] [50]. By reducing fungal colonization and sebum production, ketoconazole helps develop a more hospitable scalp for hair growth [47] [50]. Regular use of ketoconazole reduces itching, flaking, and erythema and serves as an effect adjunct to other active treatments of AGA [50].

5.3. Finasteride

Finasteride forms the backbone of the management of AGA, due to its primary action against DHT production. Finasteride is a selective type II 5α-reductase inhibitor, preventing the conversion of testosterone into DHT [34]. In fact, several studies have identified that with continued therapy, finasteride significantly improves hair density and thickness, especially over the crown and mid-scalp areas [34]. It is taken orally in a standard dosage of 1 mg daily and is approved by the FDA for the treatment of male pattern hair loss [34]. Adverse effects include impaired libido, erectile dysfunction, and gynecomastia, which, although no doubt distressing, are relatively uncommon and usually reversible on cessation [34] [51]. Due to its teratogenic effects, finasteride is contraindicated in women of childbearing age [34]. Nonetheless, finasteride remains one of the most effective pharmacological options available for arresting the progression of AGA and promoting hair regrowth in affected individuals.

5.4. Dutasteride

Dutasteride is a 5-alpha reductase inhibitor, similar to finasteride, but it inhibits both type I and type II isoforms of the enzyme, making it a significantly more potent effector [51] [52]. Dutasteride's broader mechanism of action leads to greater suppression of DHT production, increasing hair count and shaft thickness in more advanced, or treatment-resistant, cases of AGA [51]-[53]. However, dutasteride is associated with a higher side effect profile, including: sexual dysfunction, mood changes, and hormonal imbalances [53]. While highly effective, dutasteride's use requires careful patient selection and monitoring, as the potential side effects can outweigh the benefits in some individuals [53]. In women, dutasteride is rarely used due to its teratogenic risks and systemic hormonal effects.

5.5. Spironolactone

Spironolactone represents the most common oral antiandrogen for female patients with AGA, especially when associated with signs of hyperandrogenism like in PCOS [54]. Spironolactone exerts an antiandrogenic effect via AR blockade and via suppression of testosterone synthesis, effectively slowing balding and promoting follicular regrowth [55]. It has been administered in dosages ranging from 50 - 200 mg/day, depending on the severity of hair loss and the underlying hormonal profile of the patient [55]. Its use warrants caution, given the possibilities for side effects such as menstrual irregularities, mammary tenderness, dizzy spells, and

hyperkalemia [55]. Spironolactone is also contraindicated in pregnancy, due to its teratogenic properties [55]. Despite these precautions, spironolactone remains a safe and effective option for many women with AGA, offering a targeted approach to managing androgen-mediated hair loss.

5.6. Prostaglandin Analogues

Prostaglandin analogues, such as latanoprost and bimatoprost, are an innovative class of treatments originally developed for managing glaucoma [56]. These agents have been found to stimulate hair growth by extending the anagen phase and increasing hair follicle size, resulting in thicker and darker hair strands [57]. Bimatoprost, in particular, is FDA-approved for enhancing eyelash growth and is being explored for its potential in treating scalp hair loss [57]. Topical application of prostaglandin analogues allows for localized effects with minimal systemic absorption, reducing the risk of side effects [57] [58]. Early clinical studies have shown promising results, with increased hair density and improved hair quality in treated areas. However, these treatments are still in the experimental stage for AGA, and more extensive research is needed to establish their long-term safety and efficacy. Side effects, though rare, may include localized irritation or darkening of the skin around the application site [56] [59]. Prostaglandin analogues represent an exciting frontier in AGA management, offering a novel mechanism of action that complements existing therapies.

6. Surgical Management

Hair transplant is a popular and dependable approach for treating AGA, alongside other types of alopecia. During the procedure, healthcare professionals transfer androgen-resistant hair follicle units from the occipital region to areas impacted by AGA [60]. There are two predominant methods for harvesting donor's hair: hair follicular unit strip surgery (FUSS) and follicular unit extraction (FUE) [61]-[63]. FUE is the more common procedure, due to significant advantages including: less apparent scarring, increased harvestable grafts, and decreased postoperative pain [61] [62]. FUSS, however, maintains a shorter operative time, less bleeding at donor site, and allows for denser packing of follicular units leading to more favorable cosmetic results [61]-[63]. Despite the appeal of hair transplant for AGA, many patients are less than ideal candidates, including those with diffuse unpatterned alopecia, alopecia areata, insufficient hair loss, and unrealistic expectations [64]. Therefore, healthcare professionals must remain stringent in screening potential candidates.

7. Non-Pharmaceutical Management

7.1. Photobiomodulation

Photobiomodulation (PBM), commonly known as low-level light therapy (LLLT), has emerged as a non-pharmaceutical intervention for AGA by leveraging specific wavelengths of red (620 - 700 nm) and near-infrared (700 - 1440 nm) light to

stimulate cellular processes [65] [66]. These wavelengths are absorbed by chromophores within cells, triggering the production of nitric oxide (NO) and modulation of reactive oxygen species (ROS), which in turn activate redox-sensitive signaling pathways that enhance cellular proliferation, migration, and differentiation in hair follicle and perifollicular cells [65] [66]. This process helps to counteract oxidative stress and inflammation, which are key contributors to follicular miniaturization in AGA.

PBM utilizes a variety of cellular pathway signalling mechanisms. A primary mechanism underlying PBM's efficacy is the activation of mitochondrial cytochrome c oxidase, which boosts adenosine triphosphate (ATP) synthesis, thereby increasing cellular energy and supporting follicular regeneration [67]. Additionally, PBM has been shown to upregulate the Wnt/β-catenin signaling pathway, a key driver of hair follicle development and growth, while downregulating the transforming growth factor-beta (TGF-β) pathway, which contributes to follicular miniaturization and hair loss [67]. By promoting Wnt/β-catenin signaling, PBM encourages hair follicle stem cell activation, thereby extending the anagen (growth) phase of the hair cycle [67].

The therapeutic potential of PBM is supported by clinical evidence, demonstrating significant improvements in hair density and shaft diameter among patients receiving LLLT compared to controls [68]. This suggests that PBM not only prevents further hair loss but also actively contributes to hair regrowth by improving follicular function. Furthermore, PBM has been shown to enhance cell viability, proliferation, and migration in dermal papilla cells, reinforcing its role in stimulating hair growth [67]. These effects help maintain a functional hair follicle niche, ensuring continuous hair regeneration. By improving mitochondrial function, modulating critical signaling pathways, and fostering a healthier follicular microenvironment, PBM presents a promising, safe, and non-invasive strategy for managing AGA [65] [67]. The multifaceted OBM mechanism of action positions it as an effective alternative or adjunct therapy to conventional AGA treatments.

7.2. Platelet-Rich Plasma

Platelet-rich plasma (PRP) therapy has gained attention as a non-pharmaceutical treatment for androgenetic alopecia (AGA) [68] [69]. PRP is an autologous preparation of plasma with a high concentration of platelets and associated growth factors, such as platelet-derived growth factor (PDGF), epidermal growth factor (EGF), and vascular endothelial growth factor (VEGF) [69]. These growth factors are believed to promote hair growth by enhancing cellular proliferation, differentiation, and angiogenesis in hair follicles [69]. Additionally, PRP acts to support the release of growth factors that stimulate the proliferation of dermal papilla cells, prolong the anagen phase of the hair cycle, and enhance vascularization around hair follicles, leading to increased hair density and thickness [70]. Treatment with PRP leads to significant increases in hair count, hair density, and the percentage of anagen hairs, relative to controls, highlighting PRP's role in follicular regener-

ation [69]-[72]. Ultimately, PRP therapy presents a promising, safe, and effective treatment modality for AGA, with mounting clinical evidence supporting its efficacy in improving hair growth parameters.

7.3. Stem Cell Therapy

Stem cell therapy leverages the regenerative potential of various stem cell types to promote hair follicle restoration. Mesenchymal stem cells (MSCs), particularly those derived from adipose tissue and hair follicles, secrete growth factors and cytokines that stimulate dermal papilla cell proliferation, prolong the anagen phase of the hair cycle, and enhance vascularization in the perifollicular region [72] [73]. For example, MSC suspension, derived from autologous hair follicles, has been observed to contribute to notable increases in terminal hair proportion and shaft diameter, particularly benefiting patients with advanced follicular miniaturization [73]. Autologous micrografts containing adipose tissue-derived stem cells (ADSC) have also exhibited a significant increase in mean hair density improvement at 23 and 24 weeks post-treatment, with no severe side effects observed [72] [74].

In particular, ADSC-Exosome therapy serves as a promising treatment for AGA due to its potential to enhance hair follicle regeneration through multiple molecular pathways. Exosomes are small extracellular vesicles that facilitate intercellular communication by transferring proteins, lipids, and RNA, thereby influencing key biological processes in recipient cells [75] [76]. One of the primary mechanisms through which ASC-Exosomes promote hair growth is the activation of the Wnt/β-catenin signaling pathway, a critical regulator of hair follicle development and stem cell activity [75]-[77]. By increasing the expression of β-catenin and other hair growth-associated genes such as alkaline phosphatase (ALP) and versican (VCAN), ASC-Exosomes stimulate the proliferation and differentiation of dermal papilla cells, key contributors to hair follicle maintenance and growth [76] [77]. ADSC-Exosomes carrying miR-122-5p effectively counteracted DHT-induced follicular suppression while simultaneously enhancing β-catenin expression and VCAN levels [76]. Additionally, ADSC exosomes have been shown to inhibit the TGF-β/SMAD3 pathway, which is implicated in hair follicle miniaturization and AGA progression [76]. Notably, ADSC-Exosomes carrying microRNA-122-5p have also been found to antagonize the inhibitory effects of DHT on hair follicles by downregulating TGF-β1/SMAD3 signaling, thereby fostering a pro-growth follicular environment [78]. Another essential mechanism involves enhanced angiogenesis, wherein exosomes promote vascularization around hair follicles, ensuring adequate nutrient and oxygen supply for sustained hair growth [75].

Stem cell therapy, especially utilizing ADSC-Exosomes, exhibits substantial clinical evidence to back its efficacy in AGA treatment. Collectively, current literature indicates that stem cell therapy offers a promising and effective approach for AGA management, with substantial improvements in hair density, follicular

health, and overall patient satisfaction.

7.4. Current Issues with Treatments

Despite the availability of various treatments for AGA, several issues persist that limit their effectiveness and patient satisfaction. 5-alpha reductase inhibitors, such as finasteride and dutasteride, are effective, but are associated with concerns about sexual adverse effects, which can deter patients from long-term use [34] [51] [53]. Topical finasteride offers a safer alternative with fewer systemic effects, but its efficacy compared to oral formulations remains under investigation [78]. Oral minoxidil, although effective, is not FDA-approved for AGA and can cause side effects like hypertrichosis, dizziness, and lower limb edema, which may limit its use [79]. PRP therapy shows promise, but the heterogeneity in treatment protocols and lack of standardized procedures make it difficult to compare results across studies and establish definitive efficacy [78] [80]. LLLT is another non-pharmaceutical option with demonstrated efficacy, but the evidence is limited, and its effectiveness compared to other treatments or as an adjunct therapy is not well established. Emerging treatments, such as pyrilutamide and GT20029, are still in the investigational stages, and their long-term safety and efficacy need further validation [81]. Additionally, mesotherapy with dutasteride and scalp threading are newer approaches with limited evidence supporting their effectiveness, highlighting the need for more robust clinical trials [82] [83]. While the pipeline for new treatments is promising, the current landscape of AGA therapy is marked by limitations in efficacy, safety concerns, and a lack of standardized treatment protocols.

8. Future Directions

Future research in AGA is increasingly focused on uncovering its connections with systemic comorbidities and developing novel, targeted treatments. AGA has been linked to metabolic syndrome, cardiovascular disease, and insulin resistance, suggesting that it may serve as a clinical marker for broader systemic health concerns [84]. Increasing grade of AGA has been associated with an increased risk of coronary artery disease (CAD) [85]. Although the true mechanism behind this association remains unknown, it has been proposed that CAD and AGA could share a similar pattern of inheritance [86]. Nonetheless, the Alarin peptide, implicated in metabolism regulation and vasoactive biologic activity, has been noted to have receptors in dermal papillae and may represent a potential link between AGA and metabolic syndrome [87]. Insulin resistance has also been noted to play a pathogenic role in AGA by contributing to local tissue hypoxia leading to progressive hair follicle miniaturization due to microvascular insufficiency [76]. Understanding AGA pathophysiological linkage to systemic conditions could shift the perception of AGA from a cosmetic condition to a potential indicator of underlying health risks, warranting more comprehensive clinical assessment.

In parallel, emerging treatment modalities aim to move beyond traditional anti-

androgen approaches, targeting the diverse mechanisms involved in AGA progression. Regenerative therapies, such as PRP and ADSC stem cell-derived exosomes, amongst others, are being explored for their ability to stimulate hair follicle growth, reduce inflammation, and improve scalp vascularization. Although early studies are encouraging, standardized protocols and larger clinical trials are needed to validate their long-term efficacy and safety.

Advances in gene therapy and molecular targeting are also expanding the future treatment landscape. With greater understanding of the genetic factors that predispose individuals to AGA, personalized genetic therapies targeting AR sensitivity and 5α-reductase activity are becoming more feasible. Additionally, anti-inflammatory agents and immune-modulating treatments are gaining attention, given emerging evidence of localized inflammation and immune privilege collapse in AGA-affected follicles. Novel topical treatments designed to restore scalp homeostasis and protect hair follicle stem cells could complement existing therapies and slow disease progression.

The future of AGA management lies in a more personalized, multi-modal approach that integrates genetic profiling, hormonal assessments, and regenerative strategies. By addressing the various components of AGA, clinicians can offer more comprehensive and cost-efficacious treatment options for their patients. Ongoing research into the systemic implications of AGA and the development of innovative therapies will be essential not only for enhancing cosmetic outcomes, but also for broadening the scope of treatment to address underlying pathological conditions.

9. Conclusion

AGA is a complex, multifactorial condition shaped by genetic susceptibility, androgen signaling, follicular microenvironment changes, and inflammatory influences. While current treatments primarily target androgen pathways, emerging evidence supports a broader therapeutic approach that includes modulation of inflammation, lipid metabolism, and regenerative strategies. As our understanding of AGA deepens, future management will likely rely on a personalized, multimodal framework that not only addresses cosmetic concerns, but also considers the systemic impacts of the disease. Continued research is essential to refine existing therapies and reveal innovative solutions that improve both clinical outcomes and patient quality of life.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Paik, J., Yoon, J., Sim, W., Kim, B. and Kim, N. (2001) The Prevalence and Types of Androgenetic Alopecia in Korean Men and Women. *British Journal of Dermatology*, **145**, 95-99. https://doi.org/10.1046/j.1365-2133.2001.04289.x

[2] Norwood, O.T. (1975) Male Pattern Baldness: Classification and Incidence. *Southern Medical Journal*, **68**, 1359-1365. https://doi.org/10.1097/00007611-197511000-00009

[3] Norwood, O.T. (2001) Incidence of Female Androgenetic Alopecia (Female Pattern Alopecia). *Dermatologic Surgery*, **27**, 53-54. https://doi.org/10.1046/j.1524-4725.2001.00124.x

[4] Gupta, M. and Mysore, V. (2016) Classifications of Patterned Hair Loss: A Review. *Journal of Cutaneous and Aesthetic Surgery*, **9**, 3-12. https://doi.org/10.4103/0974-2077.178536

[5] Qi, J. and Garza, L.A. (2014) An Overview of Alopecias. *Cold Spring Harbor Perspectives in Medicine*, **4**, a013615. https://doi.org/10.1101/cshperspect.a013615

[6] Li, W., Cho, E., Han, J., Weinstock, M.A. and Qureshi, A.A. (2016) Male Pattern Baldness and Risk of Incident Skin Cancer in a Cohort of Men. *International Journal of Cancer*, **139**, 2671-2678. https://doi.org/10.1002/ijc.30395

[7] Cash, T.F. (1992) The Psychological Effects of Androgenetic Alopecia in Men. *Journal of the American Academy of Dermatology*, **26**, 926-931. https://doi.org/10.1016/0190-9622(92)70134-2

[8] Sinclair, R., Torkamani, N. and Jones, L. (2015) Androgenetic Alopecia: New Insights into the Pathogenesis and Mechanism of Hair Loss. *F*1000*Research*, **4**, Article 585. https://doi.org/10.12688/f1000research.6401.1

[9] van Scott, E.J. and Ekel, T.M. (1958) Geometric Relationships between the Matrix of the Hair Bulb and Its Dermal Papilla in Normal and Alopecic Scalp11 from the Dermatology Service, General Medical Branch, National Cancer Institute, National Institutes of Health, Public Health Service, U.S. Department of Health, Education and Welfare, Bethesda, Maryland. *Journal of Investigative Dermatology*, **31**, 281-287. https://doi.org/10.1038/jid.1958.121

[10] Jahoda, C.A.B. (1998) Cellular and Developmental Aspects of Androgenetic Alopecia. *Experimental Dermatology*, **7**, 235-248. https://doi.org/10.1111/j.1600-0625.2007.00666.x

[11] Heath, A.C., Nyholt, D.R., Gillespie, N.A. and Martin, N.G. (2003) Genetic Basis of Male Pattern Baldness. *Journal of Investigative Dermatology*, **121**, 1561-1564. https://doi.org/10.1111/j.1523-1747.2003.12615.x

[12] Ellis, J.A., Sinclair, R. and Harrap, S.B. (2002) Androgenetic Alopecia: Pathogenesis and Potential for Therapy. *Expert Reviews in Molecular Medicine*, **4**, 1-11. https://doi.org/10.1017/s1462399402005112

[13] Osborn, D. (1916) Inheritance of Baldness: Various Patterns Due to Heredity and Sometimes Present at Birth—A Sex-Limited Character-Dominant in Man-Women Not Bald Unless They Inherit Tendency from Both Parents. *Journal of Heredity*, **7**, 347-355.

[14] Ellis, J.A., Stebbing, M. and Harrap, S.B. (2001) Polymorphism of the Androgen Receptor Gene Is Associated with Male Pattern Baldness. *Journal of Investigative Dermatology*, **116**, 452-455. https://doi.org/10.1046/j.1523-1747.2001.01261.x

[15] Midorikawa, T., Chikazawa, T., Yoshino, T., Takada, K. and Arase, S. (2004) Different Gene Expression Profile Observed in Dermal Papilla Cells Related to Androgenic Alopecia by DNA Macroarray Analysis. *Journal of Dermatological Science*, **36**, 25-32. https://doi.org/10.1016/j.jdermsci.2004.05.001

[16] Leirós, G.J., Attorresi, A.I. and Balañá, M.E. (2012) Hair Follicle Stem Cell Differentiation Is Inhibited through Cross-Talk between Wnt/*β*-Catenin and Androgen Sig-

nalling in Dermal Papilla Cells from Patients with Androgenetic Alopecia. *British Journal of Dermatology*, **166**, 1035-1042. https://doi.org/10.1111/j.1365-2133.2012.10856.x

[17] Hillmer, A.M., Flaquer, A., Hanneken, S., Eigelshoven, S., Kortüm, A., Brockschmidt, F.F., *et al.* (2008) Genome-Wide Scan and Fine-Mapping Linkage Study of Androgenetic Alopecia Reveals a Locus on Chromosome 3q26. *The American Journal of Human Genetics*, **82**, 737-743. https://doi.org/10.1016/j.ajhg.2007.11.014

[18] Rathnayake, D. and Sinclair, R. (2010) Male Androgenetic Alopecia. *Expert Opinion on Pharmacotherapy*, **11**, 1295-1304. https://doi.org/10.1517/14656561003752730

[19] Yamazaki, M., Sato, A., Toyoshima, K., Kojima, Y., Okada, T., Ishii, Y., *et al.* (2010) Polymorphic CAG Repeat Numbers in the Androgen Receptor Gene of Female Pattern Hair Loss Patients. *The Journal of Dermatology*, **38**, 680-684. https://doi.org/10.1111/j.1346-8138.2010.01060.x

[20] Inui, S. and Itami, S. (2012) Androgen Actions on the Human Hair Follicle: Perspectives. *Experimental Dermatology*, **22**, 168-171. https://doi.org/10.1111/exd.12024

[21] Ceruti, J.M., Leirós, G.J. and Balañá, M.E. (2018) Androgens and Androgen Receptor Action in Skin and Hair Follicles. *Molecular and Cellular Endocrinology*, **465**, 122-133. https://doi.org/10.1016/j.mce.2017.09.009

[22] Sawaya, M.E. and Price, V.H. (1997) Different Levels of 5α-Reductase Type I and II, Aromatase, and Androgen Receptor in Hair Follicles of Women and Men with Androgenetic Alopecia. *Journal of Investigative Dermatology*, **109**, 296-300. https://doi.org/10.1111/1523-1747.ep12335779

[23] Trüeb, R.M. (2002) Molecular Mechanisms of Androgenetic Alopecia. *Experimental Gerontology*, **37**, 981-990. https://doi.org/10.1016/s0531-5565(02)00093-1

[24] Fu, D., Huang, J., Li, K., Chen, Y., He, Y., Sun, Y., *et al.* (2021) Dihydrotestosterone-induced Hair Regrowth Inhibition by Activating Androgen Receptor in C57BL6 Mice Simulates Androgenetic Alopecia. *Biomedicine & Pharmacotherapy*, **137**, Article ID: 111247. https://doi.org/10.1016/j.biopha.2021.111247

[25] Rebora, A. (2004) Pathogenesis of Androgenetic Alopecia. *Journal of the American Academy of Dermatology*, **50**, 777-779. https://doi.org/10.1016/j.jaad.2003.11.073

[26] Grymowicz, M., Rudnicka, E., Podfigurna, A., Napierala, P., Smolarczyk, R., Smolarczyk, K., *et al.* (2020) Hormonal Effects on Hair Follicles. *International Journal of Molecular Sciences*, **21**, Article 5342. https://doi.org/10.3390/ijms21155342

[27] Cousen, P. and Messenger, A. (2010) Female Pattern Hair Loss in Complete Androgen Insensitivity Syndrome. *British Journal of Dermatology*, **162**, 1135-1137. https://doi.org/10.1111/j.1365-2133.2010.09661.x

[28] Natarelli, N., Gahoonia, N. and Sivamani, R.K. (2023) Integrative and Mechanistic Approach to the Hair Growth Cycle and Hair Loss. *Journal of Clinical Medicine*, **12**, Article 893. https://doi.org/10.3390/jcm12030893

[29] Harrison, S. and Bergfeld, W. (2009) Diffuse Hair Loss: Its Triggers and Management. *Cleveland Clinic Journal of Medicine*, **76**, 361-367. https://doi.org/10.3949/ccjm.76a.08080

[30] Millar, S.E. (2002) Molecular Mechanisms Regulating Hair Follicle Development. *Journal of Investigative Dermatology*, **118**, 216-225. https://doi.org/10.1046/j.0022-202x.2001.01670.x

[31] Burg, D., Yamamoto, M., Namekata, M., Haklani, J., Koike, K. and Halasz, M. (2017) Promotion of Anagen, Increased Hair Density and Reduction of Hair Fall in a Clinical

Setting Following Identification of FGF5-Inhibiting Compounds via a Novel 2-Stage Process. *Clinical, Cosmetic and Investigational Dermatology*, **10**, 71-85. https://doi.org/10.2147/ccid.s123401

[32] Randall, V.A. (1994) Androgens and Human Hair Growth. *Clinical Endocrinology*, **40**, 439-457. https://doi.org/10.1111/j.1365-2265.1994.tb02483.x

[33] Nestor, M.S., Ablon, G., Gade, A., Han, H. and Fischer, D.L. (2021) Treatment Options for Androgenetic Alopecia: Efficacy, Side Effects, Compliance, Financial Considerations, and Ethics. *Journal of Cosmetic Dermatology*, **20**, 3759-3781. https://doi.org/10.1111/jocd.14537

[34] Kaufman, K.D., Olsen, E.A., Whiting, D., Savin, R., DeVillez, R., Bergfeld, W., *et al.* (1998) Finasteride in the Treatment of Men with Androgenetic Alopecia. *Journal of the American Academy of Dermatology*, **39**, 578-589. https://doi.org/10.1016/s0190-9622(98)70007-6

[35] Patel, M., Tuli, N., Patel, N. and Merja, A. (2025) A Clinical Evaluation of the Safety, Efficacy, and Tolerability of the Soulflower Rosemary Redensyl Hair Growth Serum, Tetragain™, in Healthy Female Subjects for the Treatment of Alopecia: Promoting Hair Growth and Reducing Gray Hair. *Cureus*, **17**, e77066. https://doi.org/10.7759/cureus.77066

[36] Zouboulis, C.C. (2010) Die Talgdrüse. *Der Hautarzt*, **61**, 467-477. https://doi.org/10.1007/s00105-009-1894-y

[37] Kure, K., Isago, T. and Hirayama, T. (2015) Changes in the Sebaceous Gland in Patients with Male Pattern Hair Loss (Androgenic Alopecia). *Journal of Cosmetic Dermatology*, **14**, 178-184. https://doi.org/10.1111/jocd.12153

[38] Lai, J., Chang, P., Lai, K., Chen, L. and Chang, C. (2012) The Role of Androgen and Androgen Receptor in Skin-Related Disorders. *Archives of Dermatological Research*, **304**, 499-510. https://doi.org/10.1007/s00403-012-1265-x

[39] Wang, S., Li, M., Qin, S., Wang, R., Dong, L., Wang, S., *et al.* (2024) Serum Lipidomic Changes and Sex Differences in Androgenetic Alopecia. *Heliyon*, **10**, e26204. https://doi.org/10.1016/j.heliyon.2024.e26204

[40] Choque, B., Catheline, D., Rioux, V. and Legrand, P. (2014) Linoleic Acid: Between Doubts and Certainties. *Biochimie*, **96**, 14-21. https://doi.org/10.1016/j.biochi.2013.07.012

[41] Shinzawa-Itoh, K., Aoyama, H., Muramoto, K., Terada, H., Kurauchi, T., Tadehara, Y., *et al.* (2007) Structures and Physiological Roles of 13 Integral Lipids of Bovine Heart Cytochrome C Oxidase. *The EMBO Journal*, **26**, 1713-1725. https://doi.org/10.1038/sj.emboj.7601618

[42] Jiang, G., Xu, Y., Falguières, T., Gruenberg, J. and Prestwich, G.D. (2005) Concise Synthesis of Ether Analogues of Lysobisphosphatidic Acid. *Organic Letters*, **7**, 3837-3840. https://doi.org/10.1021/ol051194w

[43] Chen, Y., Fan, Z., Wang, X., Mo, M., Zeng, S.B., Xu, R., *et al.* (2020) PI3K/Akt Signaling Pathway Is Essential for De Novo Hair Follicle Regeneration. *Stem Cell Research & Therapy*, **11**, Article No. 144. https://doi.org/10.1186/s13287-020-01650-6

[44] Lattanand, A. and Johnson, W.C. (1975) Male Pattern Alopecia a Histopathologic and Histochemical Study. *Journal of Cutaneous Pathology*, **2**, 58-70. https://doi.org/10.1111/j.1600-0560.1975.tb00209.x

[45] Jaworsky, C., Kligman, A.M. and Murphy, G.F. (1992) Characterization of Inflammatory Infiltrates in Male Pattern Alopecia: Implications for Pathogenesis. *British Journal of Dermatology*, **127**, 239-246. https://doi.org/10.1111/j.1365-2133.1992.tb00121.x

[46] Xiong, H., Tang, L., Chen, H., Wu, Y., Li, W., Wen, S., *et al.* (2023) Identification of Immune Microenvironment Changes, Immune-Related Pathways and Genes in Male Androgenetic Alopecia. *Medicine*, **102**, e35242. https://doi.org/10.1097/md.0000000000035242

[47] McKeny, P.T., Nessel, T.A. and Zito, P.M. (2023) Antifungal Antibiotics. StatPearls. https://www.ncbi.nlm.nih.gov/books/NBK538168/

[48] Bienová, M., Kucerová, R., Fiurásková, M., Hajdúch, M. and Kolář, Z. (2005) Androgenetic Alopecia and Current Methods of Treatment. *Acta Dermatovenerologica Alpina, Pannonica et Adriatica*, **14**, 5-8.

[49] Kastarinen, H., Oksanen, T., Okokon, E.O., Kiviniemi, V.V., Airola, K., Jyrkkä, J., *et al.* (2014) Topical Anti-Inflammatory Agents for Seborrhoeic Dermatitis of the Face or Scalp. *Cochrane Database of Systematic Reviews*, No. 5, CD009446. https://doi.org/10.1002/14651858.cd009446.pub2

[50] Fields, J.R., Vonu, P.M., Monir, R.L. and Schoch, J.J. (2020) Topical Ketoconazole for the Treatment of Androgenetic Alopecia: A Systematic Review. *Dermatologic Therapy*, **33**, e13202. https://doi.org/10.1111/dth.13202

[51] Estill, M.C., Ford, A., Omeira, R. and Rodman, M. (2023) Finasteride and Dutasteride for the Treatment of Male Androgenetic Alopecia: A Review of Efficacy and Reproductive Adverse Effects. *Georgetown Medical Review*, **7**. https://doi.org/10.52504/001c.88531

[52] Keam, S.J. and Scott, L.J. (2008) Dutasteride. *Drugs*, **68**, 463-485. https://doi.org/10.2165/00003495-200868040-00008

[53] Choi, G., Sim, W., Kang, H., Huh, C.H., Lee, Y.W., Shantakumar, S., *et al.* (2022) Long-term Effectiveness and Safety of Dutasteride versus Finasteride in Patients with Male Androgenic Alopecia in South Korea: A Multicentre Chart Review Study. *Annals of Dermatology*, **34**, 349-359. https://doi.org/10.5021/ad.22.027

[54] Cumming, D.C. (1990) Use of Spironolactone in Treatment of Hirsutism. *Cleveland Clinic Journal of Medicine*, **57**, 285-287. https://doi.org/10.3949/ccjm.57.3.285

[55] Aleissa, M. (2023) The Efficacy and Safety of Oral Spironolactone in the Treatment of Female Pattern Hair Loss: A Systematic Review and Meta-Analysis. *Cureus*, **15**, e43559. https://doi.org/10.7759/cureus.43559

[56] Li, T., Lindsley, K., Rouse, B., Hong, H., Shi, Q., Friedman, D.S., *et al.* (2016) Comparative Effectiveness of First-Line Medications for Primary Open-Angle Glaucoma: A Systematic Review and Network Meta-Analysis. *Ophthalmology*, **123**, 129-140. https://doi.org/10.1016/j.ophtha.2015.09.005

[57] Barrón-Hernández, Y.L. and Tosti, A. (2017) Bimatoprost for the Treatment of Eyelash, Eyebrow and Scalp Alopecia. *Expert Opinion on Investigational Drugs*, **26**, 515-522. https://doi.org/10.1080/13543784.2017.1303480

[58] Cohen, J.L. (2010) Enhancing the Growth of Natural Eyelashes: The Mechanism of Bimatoprost-Induced Eyelash Growth. *Dermatologic Surgery*, **36**, 1361-1371. https://doi.org/10.1111/j.1524-4725.2010.01522.x

[59] Wirta, D., Pariser, D.M., Yoelin, S.G., Arase, S., McMichael, A., Weng, E., Mao, C., Demos, G. and Vandenburgh, A. (2015) Bimatoprost 0.03% for the Treatment of Eyelash Hypotrichosis: A Pooled Safety Analysis of Six Randomized, Double-Masked Clinical Trials. *The Journal of Clinical and Aesthetic Dermatology*, **8**, 17-29.

[60] Kanti, V., Messenger, A., Dobos, G., Reygagne, P., Finner, A., Blumeyer, A., *et al.* (2017) Evidence-Based (S3) Guideline for the Treatment of Androgenetic Alopecia in Women and in Men—Short Version. *Journal of the European Academy of Dermatology and Venereology*, **32**, 11-22. https://doi.org/10.1111/jdv.14624

[61] Gupta, A.K., Lyons, D.C.A. and Daigle, D. (2015) Progression of Surgical Hair Restoration Techniques. *Journal of Cutaneous Medicine and Surgery*, **19**, 17-21. https://doi.org/10.2310/7750.2014.13212

[62] Kumaresan, M. and Mysore, V. (2018) Controversies in Hair Transplantation. *Journal of Cutaneous and Aesthetic Surgery*, **11**, 173-181. https://doi.org/10.4103/jcas.jcas_118_18

[63] Harris, J.A. (2013) Follicular Unit Extraction. *Facial Plastic Surgery Clinics of North America*, **21**, 375-384. https://doi.org/10.1016/j.fsc.2013.05.002

[64] Konior, R.J. and Simmons, C. (2013) Patient Selection, Candidacy, and Treatment Planning for Hair Restoration Surgery. *Facial Plastic Surgery Clinics of North America*, **21**, 343-350. https://doi.org/10.1016/j.fsc.2013.04.004

[65] Guo, Y., Qu, Q., Chen, J., Miao, Y. and Hu, Z. (2020) Proposed Mechanisms of Low-Level Light Therapy in the Treatment of Androgenetic Alopecia. *Lasers in Medical Science*, **36**, 703-713. https://doi.org/10.1007/s10103-020-03159-z

[66] Maghfour, J., Ozog, D.M., Mineroff, J., Jagdeo, J., Kohli, I. and Lim, H.W. (2024) Photobiomodulation CME Part I: Overview and Mechanism of Action. *Journal of the American Academy of Dermatology*, **91**, 793-802. https://doi.org/10.1016/j.jaad.2023.10.073

[67] Ren, Y., Li, A., Miao, X., Huo, L., Qin, H., Jiang, H., *et al.* (2025) Effects of Photobiomodulation on Human Hair Dermal Papilla Cells with Various Light Modes and Light Parameters. *Journal of Photochemistry and Photobiology B: Biology*, **262**, Article ID: 113080. https://doi.org/10.1016/j.jphotobiol.2024.113080

[68] Kim, H., Choi, J.W., Kim, J.Y., Shin, J.W., Lee, S. and Huh, C. (2013) Low-Level Light Therapy for Androgenetic Alopecia: A 24-Week, Randomized, Double-Blind, Sham Device-Controlled Multicenter Trial. *Dermatologic Surgery*, **39**, 1177-1183. https://doi.org/10.1111/dsu.12200

[69] Alves, R. and Grimalt, R. (2016) Randomized Placebo-Controlled, Double-Blind, Half-Head Study to Assess the Efficacy of Platelet-Rich Plasma on the Treatment of Androgenetic Alopecia. *Dermatologic Surgery*, **42**, 491-497. https://doi.org/10.1097/dss.0000000000000665

[70] Rodrigues, B.L., Montalvão, S.A.L., Cancela, R.B.B., Silva, F.A.R., Urban, A., Huber, S.C., *et al.* (2019) Treatment of Male Pattern Alopecia with Platelet-Rich Plasma: A Double-Blind Controlled Study with Analysis of Platelet Number and Growth Factor Levels. *Journal of the American Academy of Dermatology*, **80**, 694-700. https://doi.org/10.1016/j.jaad.2018.09.033

[71] Dubin, D.P., Lin, M.J., Leight, H.M., Farberg, A.S., Torbeck, R.L., Burton, W.B., *et al.* (2020) The Effect of Platelet-Rich Plasma on Female Androgenetic Alopecia: A Randomized Controlled Trial. *Journal of the American Academy of Dermatology*, **83**, 1294-1297. https://doi.org/10.1016/j.jaad.2020.06.1021

[72] Abdin, R., Zhang, Y. and Jimenez, J.J. (2022) Treatment of Androgenetic Alopecia Using PRP to Target Dysregulated Mechanisms and Pathways. *Frontiers in Medicine*, **9**, Article 843127. https://doi.org/10.3389/fmed.2022.843127

[73] Gan, Y., Du, L., Wang, H., Li, K., Fan, Z., Sun, P., *et al.* (2023) A Clinical Trial of Treating Androgenic Alopecia with Mesenchymal Stem Cell Suspension Derived from Autologous Hair Follicle. *Plastic & Reconstructive Surgery*, **154**, 444e-450e. https://doi.org/10.1097/prs.0000000000010841

[74] Gentile, P. (2019) Autologous Cellular Method Using Micrografts of Human Adipose Tissue Derived Follicle Stem Cells in Androgenic Alopecia. *International Journal of Molecular Sciences*, **20**, Article 3446. https://doi.org/10.3390/ijms20143446

[75] Lee, E., Choi, M.S., Cho, B.S., Won, Y.J., Lee, J.H., Kim, S.R., *et al.* (2024) The Efficacy of Adipose Stem Cell-Derived Exosomes in Hair Regeneration Based on a Preclinical and Clinical Study. *International Journal of Dermatology*, **63**, 1212-1220. https://doi.org/10.1111/ijd.17406

[76] Liang, Y., Tang, X., Zhang, X., Cao, C., Yu, M. and Wan, M. (2023) Adipose Mesenchymal Stromal Cell-Derived Exosomes Carrying miR-122-5p Antagonize the Inhibitory Effect of Dihydrotestosterone on Hair Follicles by Targeting the TGF-*β*1/SMAD3 Signaling Pathway. *International Journal of Molecular Sciences*, **24**, Article 5703. https://doi.org/10.3390/ijms24065703

[77] Tang, X., Cao, C., Liang, Y., Han, L., Tu, B., Yu, M., *et al.* (2023) Adipose-Derived Stem Cell Exosomes Antagonize the Inhibitory Effect of Dihydrotestosterone on Hair Follicle Growth by Activating WNT/*β*-Catenin Pathway. *Stem Cells International*, **2023**, Article ID: 5548112. https://doi.org/10.1155/2023/5548112

[78] Saceda-Corralo, D., Domínguez-Santas, M., Vañó-Galván, S. and Grimalt, R. (2022) What's New in Therapy for Male Androgenetic Alopecia? *American Journal of Clinical Dermatology*, **24**, 15-24. https://doi.org/10.1007/s40257-022-00730-y

[79] Bloch, L.D. and Dantas Carlos, R.M. (2024) Side Effects' Frequency Assessment of Low Dose Oral Minoxidil in Male Androgenetic Alopecia Patients. *Skin Appendage Disorders*, **11**, 14-18. https://doi.org/10.1159/000539969

[80] Katzer, T., Leite Junior, A., Beck, R. and da Silva, C. (2019) Physiopathology and Current Treatments of Androgenetic Alopecia: Going Beyond Androgens and Anti-Androgens. *Dermatologic Therapy*, **32**, e13059. https://doi.org/10.1111/dth.13059

[81] Gupta, A.K., Mays, R.R., Dotzert, M.S., Versteeg, S.G., Shear, N.H. and Piguet, V. (2018) Efficacy of Non-Surgical Treatments for Androgenetic Alopecia: A Systematic Review and Network Meta-Analysis. *Journal of the European Academy of Dermatology and Venereology*, **32**, 2112-2125. https://doi.org/10.1111/jdv.15081

[82] Bharti, J., Sonthalia, S., Patil, P. and Dhurat, R. (2017) Scalp Threading with Polydioxanone Monofilament Threads: A Novel, Effective and Safe Modality for Hair Restoration. *Journal of the European Academy of Dermatology and Venereology*, **31**, e492-e493. https://doi.org/10.1111/jdv.14336

[83] Saceda-Corralo, D., Moustafa, F., Moreno-Arrones, Ó., Jaén-Olasolo, P., Vañó-Galván, S. and Camacho, F. (2022) Mesotherapy with Dutasteride for Androgenetic Alopecia: A Retrospective Study in Real Clinical Practice. *Journal of Drugs in Dermatology*, **21**, 742-747.

[84] Chen, S., Xie, X., Zhang, G. and Zhang, Y. (2022) Comorbidities in Androgenetic Alopecia: A Comprehensive Review. *Dermatology and Therapy*, **12**, 2233-2247. https://doi.org/10.1007/s13555-022-00799-7

[85] Sharma, L., Dubey, A., Gupta, P. and Agrawal, A. (2013) Androgenetic Alopecia and Risk of Coronary Artery Disease. *Indian Dermatology Online Journal*, **4**, 283-287. https://doi.org/10.4103/2229-5178.120638

[86] Sheikh, K. (1997) Re: "Baldness and Ischemic Heart Disease in a National Sample of Men". *American Journal of Epidemiology*, **145**, 670. https://doi.org/10.1093/oxfordjournals.aje.a009167

[87] Hamed, A.M., Fatah, M.A. and Shams, G.M. (2022) Androgenetic Alopecia and Metabolic Syndrome: Is Alarin a Missing Link? *The Journal of Clinical and Aesthetic Dermatology*, **15**, 32-37.