Revolutionizing Alopecia Care: Integrating Machine Learning for Diagnosis and Treatment Optimization

Ranjeet Kumar[1], Palak Singh[1], Pallavi Pandey[1], Srishti Morris[1], Vikash Jakhmola[1]
[1]*Uttaranchal Institute of Pharmaceutical Science, Uttaranchal University, Prem Nagar, Dehradun, Uttarakhand- 248007, India.*

***Abstract*—Androgenetic alopecia is a diagnosis of hair loss that impacts both genders marked by hair thinning and specific balding patterns. It is mainly influenced by hormonal factors with dihydrotestosterone playing a role, in inhibiting the growth of hair. The condition involves an interaction of elements within the hair follicles leading to shorter and finer hairs over time. This condition can have effects on individuals it affects, impacting their quality of life and self-perception. Understanding the prevalence of alopecia in both genders is vital as rates vary among racial groups. The development and progression of this condition involve the shrinking of hair follicles due to hormone activity, particularly dihydrotestosterone. Several medical treatment options exist for women with alopecia including minoxidil and finasteride each having its effectiveness and potential side effects. Recent advancements in artificial intelligence (AI) and machine learning (ML) have revolutionized alopecia care by enabling more precise diagnosis, personalized treatment plans, and real-time monitoring of disease progression. AI-driven tools such as automated trichoscopic analysis, robotic hair transplant systems, and AI-powered Severity of Alopecia Tool (SALT) scoring automation have significantly enhanced diagnostic accuracy and therapeutic outcomes. This paper explores the integration of AI in alopecia care, highlighting its role in improving diagnostic precision, optimizing treatment strategies, and fostering advancements in personalized medicine.**

***Keywords*—Androgenetic Alopecia, Minoxidil, Baldness, Alopecia Areata, JAK inhibitors, hair transplantation, SALT Scoring, Trichoscopic Analysis, Personalized Medicine.**

I. INTRODUCTION

Androgenetic Alopecia causes thinning of scalp hair in a certain pattern, impacting both genders. Men see hair loss at the crown and front, while women keep their front hairline and get thinning at the top, making the front of their hair look wider.AGA is a genetic condition, that changes strong hairs to weaker ones. It also affects the hair cycle, leading to shorter hairs and potential balding. Early AGA occurrence links to heart and metabolic issues, and a high body mass index makes severe AGA more likely.AGA in both sexes is related to some COVID-19 cases, called the "Gabrin sign. [Nestor et al., 2021] AGA gets worse due to genes and hormones, particularly dihydrotestosterone (DHT), stopping hair growth by shortening the hair cycle's growth phase. Over time, affected hair follicles shrink, resulting in weaker, shorter hairs. Genes play a major role in AGA, but other factors like lacking vitamins, anemia, thyroid problems, or chronic illnesses should be seen as potential causes of hair loss. This paper explores the symptoms, diagnosis, treatments, and coping methods for AGA in detail. It's helpful for patients and those dealing with this condition. (Kelly et al., 2016) (Kaiser et al., 2023) The onset of AGA is gradual with cases being evident during adolescence or early adulthood stage. This can cause psychological distress leading to poor self-image and quality of life. (Ludwig et al., 1977)

With the rise of artificial intelligence (AI) and machine learning (ML), healthcare is transforming, and dermatology is no exception. Machine learning algorithms have demonstrated remarkable potential in improving alopecia care by enabling precise diagnosis, personalized treatment plans, and real-time monitoring of disease progression. In this article, we explore how machine learning is revolutionizing alopecia care by optimizing diagnosis and treatment strategies. We discuss AI-driven diagnostic tools, predictive analytics for treatment outcomes, and prospects in personalized medicine.

CLASSIFICATION OF ANDROGENIC ALOPECIA

There are seven stages of its evolution: hair loss on the vertex follows hair loss in the frontotemporal region. Men may also experience widespread crown thinning in some situations, but they will still have

the frontal hairline, similar to the Ludwig Classification pattern (Shankar et al., 2009).

There are several commonly used classifications for female pattern hair loss (FPHL).

1. Ludwig's Classification: Based on hair density, this approach classifies the disorder into three progressive stages: minimal alopecia (Stage I), moderate alopecia (Stage II), and severe alopecia (Stage III) (Ludwig et al., 1977)(Savin et al., 1992).

2. Ebling's Classification: For female androgenetic alopecia (FAGA), Ebling's system consists of five stages. Ludwig's system is in line with Stages I and II(Olsen et al., 1994) (Hong et al., 2013). While the frontal temporal recession is evident in Stage IV, Stage III exhibits diffuse hair loss and beginning frontotemporal hairline loss. Stage V is similar to male pattern baldness (MPHL), (Zhao et al., 2013).

PHYSIOLOGICAL IMPACTS OF AGA

Androgenetic Alopecia (Aga)causes hair thinning (leading eventually to complete baldness) because hairs in this state are too small for them to come out from the pores as they should do after growing up as well as developing their various kinds (root, stem, etc). (Gupta, & Mysore, 2016)Moreover, this problem can be defined as genetic hormonal environmental factors (Androgenetic alopecia (Aga) (Ogata, 1953, p.102). AGA is characterized by the gradual reduction in size and the subsequent loss of hair follicles which eventually leads to thinning out on one's head, and baldness at capacity. Androgens like testosterone and its derivative dihydrotestosterone (DHT), are the main hormonal influences in AGA (Ludwig, 1977). This further implies that; the hair growth cycle starts getting shorter with time leading to smaller and much softer hair until follicles no longer grow hair (Savin, 1992, p. A461).

THE STUDY OF DISEASE TRANSMISSION

MALE

Male androgenetic alopecia is transferred from one person to another, this paper explores genetic and hormonal mechanisms that govern the development of this condition which leads to hair thinning over time (Ogata,1953, p. 102). Even though androgenetic alopecia does not spread through contact as infectious diseases do, it can be transmitted through genetics or influenced by hormones that make it happen. Studies have indicated that androgenetic alopecia has a substantial hereditary element, with modes of inheritance being evident in terms of their maternal and paternal lines (Nestor et al., 2021) (Savin, 1992, p. A461). When it comes down to it, several different genetic markers or polymorphisms are responsible for causing certain people to be more susceptible to this condition than others.

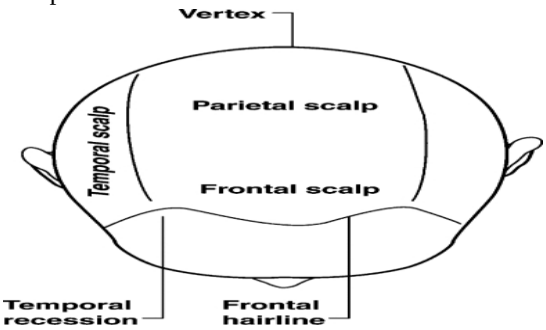

Figure 1: -Illustrating different sections of the scalp.

FEMALE

According to the studies that have been conducted on hair diseases and their causes, this condition is said to be passed on from parents to their offspring through genes and other conditions linked with the environment (Gupta& Mysore,2016, p. 10) (Ludwig, 1977). Genetic predisposition variably leads to high androgenetic alopecia instructional income patterns as indicated by the research findings. But other causes of disease are just as important in disease development and movement. These include factors such as stress, diet, or lifestyle (Hong et al., 2013). Also, female androgenetic alopecia is contributed to by hormonal fluctuations notably high levels of androgens like testosterone. One way we might learn about disease dissemination is by looking at how these abnormal levels of hormones relate to genetic predisposition (Farivar et al., 2014).

PATHOGENESIS

The increasing miniaturization of hair follicles is its defining characteristic leading to thinning of the hair and eventually to baldness. Several factors contribute to the onset of androgenetic alopecia, including genetics, hormonal imbalances, and follicular sensitivity to the hormone dihydrotestosterone (DHT) (Nowak et al., 2008).

1. Hormonal Imbalances: Androgens, particularly DHT, People having hair loss possess a genetic makeup. Hormonal imbalances, such as an increase in DHT levels or an altered androgen receptor sensitivity, can contribute to the progression of hair loss (Sinclair et al., 2015).

2. Follicular Sensitivity: - Hair follicles in individuals with androgenetic Individuals with alopecia have a genetic predisposition that makes them more responsive to the effects of dihydrotestosterone (DHT). This sensitivity causes the follicles to undergo a process called miniaturization, where they become progressively smaller and produce finer hairs until they eventually stop producing hair altogether (Cuevas-Diaz Duran et al., 2024).

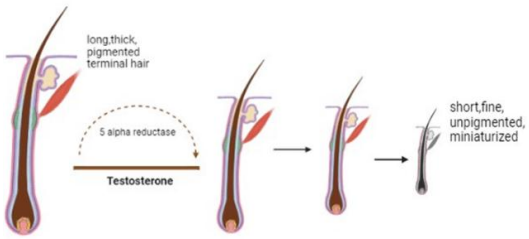

Figure 2:-Pathogenesis of androgenetic Alopecia

MEDICAL TREATMENT OF AGA IN WOMEN

MINOXIDIL

As per Price (1999), the only medicine approved by the FDA to help hair grow in women with AGA is minoxidil solution applied on the scalp. Tests using double-blind, placebo-controlled methods showed it works (Fertig et al., 2017). Hair amounts and weight were the main measures (Price, 1999). Women using minoxidil had more hair and heavier hair than those using a fake treatment. (Mirmirani et al., 2015) In a double-blind study done on women between 22 to 41 years using a 2% minoxidil solution there was a big rise in hair weight at 16 weeks compared to fake treatment (Price and Menefee, 1990). It's key to know that it might take 6–12 months for hair to become longer and thicker (Sun et al., 2020). Use minoxidil solution twice daily on a dry scalp.

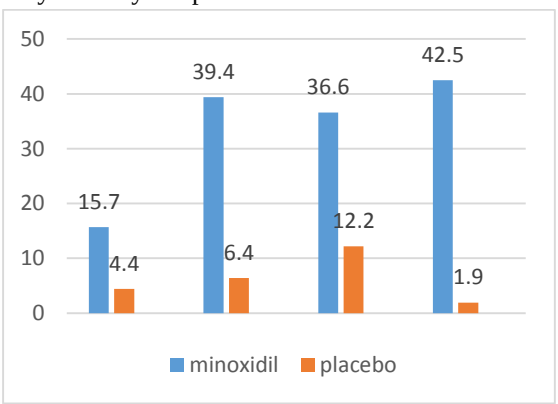

Figure 3:- The average alteration in hair weight observed in women who applied a 2% topical minoxidil solution twice daily over 32 weeks.

FINASTERIDE

Finasteride is not prescribed for use by pregnant females or females who may become pregnant because it can cause abnormalities in male fetuses. Studies have found that it is not effective in treating hair thinning in postmenopausal women (Sawaya, M. E., & Price, 1997).

NEW COMING TREATMENT OPTIONS

1. Platelet-rich plasma (PRP) Therapy: - This involves taking concentrated platelets from your blood and injecting them into your scalp. The platelets are thought to stimulate the growth of hair (Price, 2003, p. 25)

2. Stem Cell Therapy: -This treatment is also being researched, and it's based on the theory that your stem cells can regenerate the hair follicle and help grow new hair.

3. Topical JAK Inhibitors: -JAK inhibitors are drugs that are used to treat various autoimmune diseases, such as rheumatoid arthritis, as well as alopecia areata. Scientists are also studying whether they can help treat androgenetic alopecia.

4. Nutritional Supplements: - Some minerals and vitamins also support healthy hair growth, like biotin, zinc, and iron. People are also being studied to see if they can help people with androgenetic alopecia.

Artificial Intelligence in Alopecia Care

AI into alopecia leads to the development of several innovative tools aimed at enhancing diagnosis and treatment some AI applications in this field are:

1. ARTAS Robotic Hair Transplant System: This FDA-approved system utilizes AI and machine learning to assist in hair transplantation procedures. It identifies and extracts optimal donor hair follicles with minimal scarring and determines ideal recipient sites by analyzing scalp data, thereby improving precision and efficiency in hair restoration surgeries. (Duraisamy P et al., 2024)

2. AI Algorithms for Trichoscopic Analysis: Machine learning models, such as Support Vector Machines (SVM), have been developed to analyze trichoscopic images. These algorithms classify patients based on hair characteristics and calculate severity indices, aiding dermatologists in assessing androgenic alopecia (AGA) severity and tailoring appropriate therapies. (Di Fraia M et al., 2023)

3. AI-Powered SALT Scoring Automation: AI systems have been created to automate the Severity

of Alopecia Tool (SALT) scoring by analyzing scalp images. This automation reduces subjectivity and interobserver variability, providing consistent and objective assessments of hair loss severity. (Nguyen H et al., 2025)

4. GAIA Mobile Application: The "Generating Artificial Intelligence Assisted Assessment for Alopecia" (GAIA) app is under development to offer early diagnosis and monitoring of alopecia. It employs AI algorithms for objective measurement of hair loss, serving as a point-of-care tool for individuals with alopecia. (Raymond, O et al., 2024)

5. Kolmar Korea's AI Diagnostic Solution: Kolmar Korea has developed an AI-based diagnostic tool that analyzes scalp biomarkers to identify 16 types of androgenic hair loss. This solution enables dermatologists to determine the specific causes of a patient's hair loss, facilitating personalized treatment strategies.

TREATMENTS

METHOD	DRUG	FUNCTION	SIDE EFFECTS	RECEPTORS
TOPICAL	Minoxidil	increase the amount of intracellular calcium, which up-regulates the enzyme adenosine triphosphate (ATP) synthase, promoting stem cell differentiation(Nestor et al., 2021) (Kaiser et al., 2023)	Irritant and allergic contact dermatitis, facial hypertrichosis, pruritus	androgenetic receptors (AR) new targets, aromatase (CYP19A1) (Kanti et al., 2018)
ORAL	Finasteride	inhibiting Type II 5-alpha-reductase enzyme (Wang et al., 2017)	skin erythema and contact dermatitis, increased liver enzymes, and anxiety (Cash et al., 1993).	inhibitor of 5-α-reductase (Kaiser et al., 2023)
	Cyproterone acetate	The primary function of AGA lies in its ability to counteract androgen impact such as testosterone and DHT on the hair follicles (Ludwig1977, p. 247)(Nestor et al., 2021)	One of the functions is improvement in blood circulation, metabolism enhancement, and prolongation of the anagen phase(Cash et al., 1993)	They include cytochrome P450 metabolism (Kaiser et al., 2023)
LIGHT THERAPIES	Low-level laser therapy	Among the functions are more significant blood flow, enhancing cellular metabolism, and anagen extension phase elongation (Aronson et al., 2009) (Kanti et al., 2018)	Temporary hair sheeding and scalp pruritus(itching) (Gonshor,2002)	
	Hair transplantation	Pain, Scarring, Swelling, Bleeding,	Side effects include scarring, itching,	

		Itching (Gonshor,2002)	infection, folliculitis, altered sensation, bleeding, pain, and discomfort (Aronson et al., 2009) (Kanti et al., 2018)	

SUPPLEMENTATION AND OVER THE COUNTER DRUGS	Synergen complex part of oral nutraceutical supplements.	There are some side effects like allergies.	Reduce inflammation (Nestor et al., 2021) (Said et al., 2020)

II. CONCLUSION

Androgenetic alopecia ranks among the most frequent concerns in dermatology prompting patients to seek treatment. AGA can cause notable emotional strain for those affected. Dermatologists should grasp the diagnosis and treatment procedures for AGA. The integration of artificial intelligence in alopecia care marks a significant breakthrough in dermatology, offering innovative solutions for accurate diagnosis, personalized treatment, and continuous disease monitoring. AI-powered diagnostic tools, such as trichoscopic analysis and SALT scoring automation, have streamlined the evaluation of alopecia severity while reducing observer variability. Additionally, robotic hair transplantation and predictive analytics for treatment response enhance therapeutic outcomes, making hair restoration procedures more effective and precise. The future of alopecia management lies in leveraging AI to further refine diagnostic capabilities, optimize treatment protocols, and develop novel therapeutic interventions. Continued research and collaboration between AI experts and dermatologists will be essential in unlocking the full potential of AI-driven technologies in alopecia care, ultimately improving patient outcomes and advancing the field of hair restoration medicine.

REFERENCES

[1] Aronson, J. K., & Ramachandran, M. (2009). The diagnosis of art: Van Gogh and male pattern baldness. *Journal of the Royal Society of Medicine*, *102*(1), 32-33.

[2] Cash, T. F. (1992). The psychological effects of androgenetic alopecia in men. Journal of the American Academy of Dermatology, 26(6), 926-931.

[3] Cash, T. F., Price, V. H., & Savin, R. C. (1993). Psychological effects of androgenetic alopecia on women: comparisons with balding men and with female control subjects. Journal of the American Academy of Dermatology, 29(4), 568-575.

[4] Cuevas-Diaz Duran, R., Martinez-Ledesma, E., Garcia-Garcia, M., Bajo Gauzin, D., Sarro-Ramírez, A., Gonzalez-Carrillo, C., ... & Cardenas-Lopez, A. (2024). The biology and genomics of human hair follicles: a focus on androgenetic alopecia. *International Journal of Molecular Sciences*, *25*(5), 2542.

[5] Di Fraia M, Tieghi L, Magri F, Caro G, Michelini S, Pellacani G, Rossi A. A machine learning algorithm applied to trichoscopy for androgenic alopecia staging and severity assessment. Dermatology Practical & Conceptual. 2023 Jul 1;13(3):e2023136.

[6] Duraisamy P, Vidhya V, Preetha T, Niranjani V. Implementing Machine Learning Techniques for Hair Health Prediction in Follicle Futures. In2024 Second International Conference on Data Science and Information System (ICDSIS) 2024 May 17 (pp. 1-6). IEEE.

[7] Farivar, S., Malekshahabi, T., &Shiari, R. (2014). Biological effects of low level laser therapy. *Journal of lasers in medical sciences*, *5*(2), 58.

[8] Fertig, R. M., Gamret, A. C., Darwin, E., &Gaudi, S. (2017). Sexual side effects of 5-α-reductase inhibitors finasteride and dutasteride: A comprehensive review. Dermatology online journal, 23(11).

[9] Gonshor, A. (2002). Technique for producing platelet-rich plasma and platelet concentrate:

background and process. *International Journal of Periodontics & Restorative Dentistry*, *22*(6).

[10] Gupta, M., & Mysore, V. (2016). Classifications of patterned hair loss: a review. *Journal of cutaneous and aesthetic surgery*, *9*(1), 3-12.

[11] Ho, C. H., Sood, T., & Zito, P. M. (2017). Androgenetic alopecia.

[12] Hong, H., Ji, J. H., Lee, Y., Kang, H., Choi, G. S., & LEE, W. S. (2013). Reliability of the pattern hair loss classifications: A comparison of the basic and specific and N orwood–H amilton classifications. *The Journal of dermatology*, *40*(2), 102-106.

[13] https://m.koreaherald.com/article/3420552

[14] Kaiser, M., Abdin, R., Gaumond, S. I., Issa, N. T., & Jimenez, J. J. (2023). Treatment of androgenetic alopecia: current guidance and unmet needs. *Clinical, Cosmetic and Investigational Dermatology*, 1387-1406.

[15] Kanti, V., Messenger, A., Dobos, G., Reygagne, P., Finner, A., Blumeyer, A., & Blume-Peytavi, U. (2018). 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(1), 11-22.

[16] Kelly, Y., Blanco, A., & Tosti, A. (2016). Androgenetic alopecia: an update of treatment options. *Drugs*, *76*, 1349-1364.

[17] Ludwig, E. (1977). Classification of the types of androgenetic alopecia (common baldness) occurring in the female sex. *British Journal of Dermatology*, *97*(3), 247-254.

[18] Mercuri, S. R., Paolino, G., Di Nicola, M. R., &Vollono, L. (2021). Investigating the safety and efficacy of platelet-rich plasma (PRP) treatment for female androgenetic alopecia: review of the literature. *Medicina*, *57*(4), 311.

[19] Mirmirani, P., Consolo, M., Oyetakin-White, P., Baron, E., Leahy, P., & Karnik, P. (2015). Similar response patterns to topical minoxidil foam 5% in frontal and vertex scalp of men with androgenetic alopecia: a microarray analysis. *British Journal of Dermatology*, *172*(6), 1555-1561.

[20] Nestor, M. S., Ablon, G., Gade, A., Han, H., & Fischer, D. L. (2021). Treatment options for androgenetic alopecia: Efficacy, side effects, compliance, financial considerations, and ethics. *Journal of cosmetic dermatology*, *20*(12), 3759-3781.

[21] Nguyen H, Gazeau L, Wolfe J. Using artificial intelligence to compute Severity of Alopecia Tool scores. JAAD international. 2025 Feb 1;18:101-2.

[22] Nowak, J. A., Polak, L., Pasolli, H. A., & Fuchs, E. (2008). Hair follicle stem cells are specified and function in early skin morphogenesis. *Cell stem cell*, *3*(1), 33-43.

[23] Ogata, T. (1953). Development of patterned alopecia. *Sogo Rinsho*, *2*(2), 101-106.

[24] Olsen, E. A. (1994). Disorders of hair growth: diagnosis and treatment. *(No Title)*.

[25] Price, V. H. (1999). Treatment of hair loss. New England Journal of Medicine, 341(13), 964-973.

[26] Price, V. H. (2003, June). Androgenetic alopecia in women. In *Journal of Investigative Dermatology Symposium Proceedings* (Vol. 8, No. 1, pp. 24-27). Elsevier.

[27] Price, V. H., Roberts, J. L., Hordinsky, M., Olsen, E. A., Savin, R., Bergfeld, W., &Waldstreicher, J. (2000). Lack of efficacy of finasteride in postmenopausal women with androgenetic alopecia. Journal of the American Academy of Dermatology, 43(5), 768-776.

[28] Raymond, O., Shaik, J., Rypka, K., Farah, R. S., Bellefeuille, G., & Hordinsky, M. (2024). Use of artificial intelligence to track platelet-rich plasma treatment outcomes in females with nonscarring alopecia: A case series. *JAAD Case Reports*, *47*, 103-106.

[29] Said, M., El-Sayed, S. K., & Elkhouly, N. D. E. (2020). Trichoscopic evaluation of frontal hairline recession in Egyptian female patients. *Journal of Cosmetic Dermatology*, *19*(10), 2706-2716.

[30] Savin, R. C. (1992, April). A method for visually describing and quantitating hair loss in male pattern baldness. In *CLINICAL RESEARCH* (Vol. 40, No. 2, pp. A461-A461). 6900 GROVE RD, THOROFARE, NJ 08086 USA: SLACK INC.

[31] Sawaya, M. E., & 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(3), 296-300.

[32] Shankar, D. K., Chakravarthi, M., &Shilpakar, R. (2009). Male androgenetic alopecia:

population-based study in 1,005 subjects. *International journal of trichology*, *1*(2), 131-133.

[33] Sinclair, R., Torkamani, N., & Jones, L. (2015). Androgenetic alopecia: new insights into the pathogenesis and mechanism of hair loss. *F1000Research*, *4*(F1000 Faculty Rev).

[34] Sun, H. Y., & Sebaratnam, D. F. (2020). Clascoterone as a novel treatment for androgenetic alopecia. *Clinical and Experimental Dermatology*, *45*(7), 913-914.

[35] Zhao, L., & Cao, D. (2023). Application of hair transplantation combined with platelet-rich plasma injection for the treatment of androgenic alopecia. *European Journal of Dermatology*, *33*(5), 544-549.