

Advances in Treatment for Hair Loss



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Abstract

Hair loss, or alopecia, comprises a diverse group of disorders with distinct underlying mechanisms and clinical presentations. It is broadly classified into non-cicatricial (non-scarring) and cicatricial (scarring) alopecia, with the potential for regrowth depending on preservation of the hair follicle. Current management includes established pharmacological treatments such as minoxidil and finasteride, alongside combination therapy and emerging approaches targeting hair-follicle biology. Advances in drug delivery, injectable and regenerative treatments, cell-based therapies, extracellular vesicles, targeted therapies for non-scarring alopecias, gene therapy, tissue engineering, and hair restoration have expanded the therapeutic landscape. However, these approaches differ in their level of clinical evidence and maturity. Standardization of treatment protocols, comparative clinical studies, and longer-term evaluation remain important for defining the clinical role of emerging therapies.

Keywords

Hair loss; Androgenetic

alopecia; Minoxidil; Finasteride; Regenerative medicine; Hair transplantation

Introduction

Hair loss is broadly classified into non-cicatricial and cicatricial alopecia. Non-cicatricial alopecia is characterized by preserved hair-follicle integrity and potential for regrowth, whereas cicatricial alopecia involves follicular destruction and irreversible hair loss. Among non-scarring disorders, androgenetic alopecia (AGA) and alopecia areata (AA) differ in their underlying mechanisms and clinical presentation.^{1,2} Hair growth is regulated through the anagen, catagen, telogen, and exogen phases, and disturbances in this cycle contribute to altered hair growth and shedding.¹

Current pharmacological treatment of AGA includes minoxidil and finasteride.² Minoxidil is converted to minoxidil sulfate and acts, among other mechanisms, through potassium-channel activation, whereas finasteride inhibits type II 5 α -reductase and reduces conversion of testosterone to

dihydrotestosterone.² Hair loss may recur following treatment discontinuation. These limitations have prompted investigation into additional pharmacological, regenerative, and technology-based approaches. Molecular targets under investigation include the androgen receptor, Wnt/ β -catenin, JAK/STAT, and CXCL12/CXCR4 pathways.²

The expanding treatment landscape therefore includes established therapies as well as approaches directed toward drug delivery, follicular regeneration, molecular pathways, and hair restoration.

Treatment According to Alopecia Type

Treatment approaches differ according to the underlying alopecia. Recent research has examined AGA, AA, and other non-scarring alopecias as distinct therapeutic settings.³

Androgenetic Alopecia

Minoxidil and finasteride remain established pharmacological treatments for AGA. Their differing mechanisms provide a rationale for combination therapy. Clinical studies have evaluated combinations involving minoxidil and finasteride, with some reporting better hair-growth outcomes than individual treatments. However, differences in study design, treatment regimens, outcome measures, and follow-up limit direct comparison across studies.⁴

Research has also expanded toward additional molecular targets, including Wnt/ β -catenin, JAK/STAT, CXCL12/CXCR4, and androgen-related pathways. Small-molecule inhibitors, biologic therapies, antibody-

based approaches, and cell-based strategies such as stem-cell transplantation and dermal papilla-cell regeneration have been investigated.²

Alopecia Areata

AA has a different therapeutic framework, with research focusing on immune and inflammatory pathways. JAK/STAT signaling has been investigated in relation to AA pathogenesis and as a therapeutic target. JAK inhibitors are among the targeted treatments evaluated in AA, with studies examining their efficacy and safety.³

Telogen Effluvium

Telogen effluvium represents another form of non-scarring alopecia in which the hair cycle provides an important biological framework. The transition between anagen, catagen, telogen, and exogen phases is associated with changes in hair growth and shedding when the cycle is disturbed.¹ TE requires consideration of its underlying mechanisms and clinical characteristics.³ Typically acute TE and chronic TE have different clinical characteristics and require different treatment approaches.

Established and Emerging Pharmacological Approaches

Minoxidil and finasteride remain the established pharmacological treatments for AGA.² Their complementary mechanisms have supported investigation of combination regimens, although variation between clinical studies limits direct comparison of outcomes.⁴

Beyond these agents, drug development has expanded toward small-molecule

inhibitors, biologics, antibody-based therapies, and cell-based approaches directed toward hair-follicle regulation. The therapeutic landscape is therefore moving from established pharmacological stimulation and androgen modulation toward approaches targeting specific molecular and cellular pathways. However, these newer strategies remain at different stages of investigation.²

Advances in Drug Delivery

Drug delivery has emerged as an important area of development because conventional cutaneous delivery is affected by the skin barrier. Novel formulations, nanotechnology-based systems, and microneedle platforms have therefore been investigated to improve delivery toward relevant sites and potentially the hair follicle.^{2,5}

Nanotechnology-based systems include liposomes, nanoparticles, nanostructured lipid carriers, and other lipid-based systems. Alternative formulations of finasteride and dutasteride, topical approaches, and nanoparticle-based delivery have also been investigated.^{2,5}

Microneedles can penetrate the stratum corneum and facilitate delivery of bioactive substances toward the hair follicle. Their application has been investigated for minoxidil and finasteride, as well as exosomes and growth factors.^{2,5} The associated mechanical stimulation has also been examined in relation to hair growth.

An important consideration is that several advanced delivery systems, particularly

nanocarrier- and microneedle-based approaches, remain primarily investigational or preclinical. Further research is required to establish their clinical applicability.⁵

Procedural therapies: from “adjunct” to evidence-informed combination therapy

Platelet-Rich Plasma

PRP is an autologous preparation containing platelets and associated biological mediators and has been investigated for potential effects on the follicular environment.¹

A 2024 systematic review and meta-analysis found that adding PRP to topical minoxidil can improve clinical outcomes compared with minoxidil alone, supporting its use as an adjunct in appropriately selected patients.⁹

The major limitation in interpreting PRP evidence is protocol heterogeneity. Studies differ in preparation methods, platelet concentrations, activation procedures, administration techniques, and treatment schedules. These differences can substantially alter the intervention being evaluated and make direct comparison between studies difficult. The available literature therefore does not establish a single standardized PRP preparation or treatment protocol for hair loss.¹

Microneedling and Photobiomodulation

Microneedling may enhance growth through wound-healing signals and may facilitate delivery of topical agents. Evidence suggests benefit

when added to minoxidil, but technique and treatment schedules vary. It should be regarded as an adjunct rather than a stand-alone first-line treatment.

Low-level light therapy/photobiomodulation has a more established mechanistic rationale than many consumer “growth” devices, with proposed effects on mitochondrial signaling, cellular metabolism and the anagen phase. Its effect is generally modest and requires consistent use. Device quality, wavelength, fluence and treatment schedule matter; marketing claims should not be equated with clinical evidence.

Cell-Based and Regenerative Approaches

Cell-based approaches have investigated stem cells and hair-follicle cell populations including dermal papilla cells, dermal sheath cells, and hair-follicle stem cells. Their proposed application relates to hair-follicle development, maintenance, and regulation of the hair cycle. Growth factors and extracellular vesicles have also been investigated for their potential involvement in hair-follicle function and maintenance of the anagen phase. These approaches extend treatment research toward regeneration of the follicular environment rather than conventional pharmacological stimulation. However, questions concerning standardization, application, and clinical translation remain.⁶

Extracellular Vesicles and Exosome-Based Approaches

Extracellular vesicles (EVs) and exosome-related approaches

have been investigated in hair-loss treatment because EVs participate in intercellular communication and can contain biologically active molecules. Their potential application in hair regeneration has therefore been studied in relation to hair-follicle signaling and function.^{1,6}

Growth-factor-based approaches have similarly been investigated in regenerative and injectable strategies.⁶ The characteristics and preparation of EVs, exosomes, and growth-factor-based interventions can vary between studies, contributing to heterogeneity in the available evidence.^{1,6} Standardized preparations, treatment protocols, and clinical outcomes remain necessary to better define their therapeutic role.

Gene Therapy and Tissue Engineering

Gene therapy and tissue engineering represent further approaches to hair regeneration. Gene-based strategies have been investigated in relation to molecular pathways involved in hair-follicle development and function, while tissue engineering has focused on the development and regeneration of hair-follicle structures. Research includes approaches involving cells and biomaterials designed to support follicular formation or regeneration. These strategies differ from conventional pharmacological treatment by targeting cellular, molecular, or structural aspects of the follicle. However, these approaches remain under development and require further research to establish their clinical applicability.⁶

Hair Restoration and Transplantation

Hair transplantation remains an established approach to hair restoration. Follicular unit transplantation (FUT) and follicular unit extraction (FUE) are established surgical techniques. FUE involves extraction of individual follicular units from the donor area, whereas FUT involves removal of a strip of donor tissue followed by preparation of follicular units for transplantation.^{7,8}

Advances have included improvements in donor-area assessment, hairline design, follicular-unit placement, and use of the available donor supply. Diagnostic imaging and artificial-intelligence-supported assessment have also been incorporated into hair-restoration practice for assessment and treatment planning.⁷

Toward Individualized and Multimodal Treatment

The current treatment landscape encompasses pharmacological, procedural, regenerative, biomedical, and surgical approaches.

For AGA, established pharmacological therapy remains centered on minoxidil and finasteride, with combination regimens investigated because of their complementary mechanisms.⁴ Targeted approaches such as JAK inhibitors have been investigated in AA, while drug-delivery technologies aim to improve delivery toward the hair follicle.^{2,5}

PRP, cell-based therapies, extracellular vesicles,

exosomes, and growth factors represent additional regenerative approaches.^{1,6} Hair transplantation remains an established surgical option, with advances in assessment and planning contributing to refinement of restoration procedures.^{7,8}

The evidence, however, is not uniform. Established treatments coexist with emerging interventions whose preparation, protocols, efficacy, and clinical applicability remain under investigation.^{1,6}

For clinical practice, the distinction between established and emerging approaches is therefore important when considering their place within individualized or multimodal treatment.

Future Perspectives

Targeted drug development, advanced drug-delivery systems, and regenerative approaches remain active areas of investigation.^{2,5} Small-molecule therapies, biologics, cell-based approaches, nanocarriers, and microneedle systems are being explored to address different aspects of hair-follicle biology and therapeutic delivery.^{2,5}

Stem-cell and hair-follicle-cell approaches, extracellular vesicles, gene therapy, and tissue engineering represent additional areas of investigation.⁶ Their translation into clinical practice will require greater standardization, evaluation of safety and efficacy, and longer-term clinical assessment.

Comparative studies and standardized treatment protocols will be important in

determining which emerging approaches ultimately acquire a defined role in hair-loss management.^{1,4,6}

Conclusion

The treatment landscape for hair loss has expanded beyond established pharmacological and surgical approaches to include combination therapy, advanced drug delivery, injectable and regenerative treatments, targeted therapies, cellular approaches, and tissue engineering.

Minoxidil and finasteride remain established treatments for AGA, while combination pharmacotherapy and additional molecular targets continue to be investigated.^{2,4} Targeted approaches such as JAK inhibitors have expanded treatment research in AA, while hair cycle pattern alteration remains relevant to non-scarring disorders such as TE.³

Nanocarriers and microneedle systems are being investigated to improve therapeutic delivery, while PRP, cell-based approaches, extracellular vesicles, exosomes, and growth factors represent developing regenerative strategies.^{1,2,5,6} Gene therapy and tissue engineering extend research toward molecular and structural follicular regeneration.⁶ Hair transplantation remains an established component of hair restoration.^{7,8}

The key consideration across this expanding landscape is the differing level of evidence and clinical maturity. Continued standardization and well-designed clinical studies will be required to define the

appropriate role of emerging treatments in hair-loss management.

Author's Experience:

A 360 degree multimodal approach towards treatment of hair loss including pharmacological therapy, diet and lifestyle modifications (avoidance of smoking, hair growth promoting balanced diet including antioxidants, proteins, omega-3-fatty acids, hydration, de-stressing techniques), scalp

inflammation management and appropriate procedural intervention (as needed) give most optimal results. Interesting new treatment options like exosomes deserve cautious optimism at current stage of development.

Declarations

Conflict of Interest

The author declares no conflict of interest.

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Author Contributions

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