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Journal of Cutaneous and Aesthetic Surgery

Article in Press

Review Article

Laser therapies in androgenetic alopecia: Review and clinical experiences

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Received: 11 September 2024
Accepted: 29 October 2024
Epub Ahead of Print: 29 January 2025
Published:

DOI
10.25259/JCAS_73_2024

Quick Response Code:

ABSTRACT

The exploration of treatment modalities for androgenetic alopecia (AGA) reveals a range of options, each with unique benefits. Traditional treatments such as minoxidil and finasteride are effective but have limitations, leading to the exploration of laser options. Low-level laser therapy, Food and Drug Administration approved, shows promise through photobiomodulation, while 675 nm red light lasers enhance hair density by targeting collagen and extending the anagen phase. Fractional lasers, including CO_2, erbium-doped yttrium aluminum garnet (Er:YAG) and Er: glass, play a significant role in collagen remodeling, enhancing drug delivery, and activating growth pathways. Non-ablative lasers such as pico and thulium stimulate hair follicles with minimal downtime. Combining these lasers with minoxidil or platelet-rich plasma has shown varied outcomes, highlighting the need for personalized approaches. Overall, this review seeks to present dermatologists and patients with a comprehensive overview of the latest advancements in laser therapy for AGA, detailing their mechanisms, safety, and efficacy, as supported by recent clinical studies.

Keywords: Androgenetic alopecia, Low-level laser therapy, CO_2 laser, Er:YAG, Er: Glass, Picosecond laser, Thulium laser

INTRODUCTION

Androgenetic alopecia (AGA), commonly known as male or female pattern baldness. It causes severe psychological and emotional distress in an individual, especially in young males and females. AGA is a multifactorial condition influenced by several factors: (1) Genetics: Specific loci on chromosomes 2, 3, and 20 are linked to hair follicle (HF) development, playing a key role in AGA.[1,2] (2) Hormones: Dihydrotestosterone, derived from testosterone, binds to androgen receptors in HFs, causing miniaturization and hair loss. Genetic variations in androgen metabolism and receptor sensitivity also contribute to AGA.[3,4] (3) Environment and Lifestyle: Factors such as diet and stress can influence the severity of AGA. (4) Molecular Mechanisms: Abnormal androgen signaling, disrupted cell proliferation, and dysregulated WNT/β-catenin pathways drive AGA progression. (5) Inflammation and oxidative stress exacerbate HF damage and worsen the condition.[5,6]

Current conventional treatments for AGA include topical minoxidil and oral finasteride, both Food and Drug Administration (FDA)-approved therapies. Minoxidil, a medication widely used to promote hair growth, stimulates the production of vascular endothelial growth factor (VEGF), enhancing blood vessel formation with increased flow due to vasodilatory effect and hair growth.[7]

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Despite its effectiveness, some individuals do not respond to minoxidil or finasteride.[8] The main drawback of these drugs is long-term usage, which leads to adherence issues. In addition, minoxidil can cause side effects such as scalp irritation, allergic contact dermatitis, and hypertrichosis. On the other hand, oral finasteride can cause decreased libido, erectile dysfunction, decreased ejaculate volume, and potentially irreversible adverse effects leading to post-finasteride syndrome. It is also associated with a teratogenic risk, making it unsuitable for use by pregnant women. Other serious side effects include gynecomastia and an increased risk of male breast cancer.[9]

This review article aims to discuss the trend in laser treatment in AGA: low-level laser therapy (LLLT), 675 nm, fractional pico, fractional CO_2, fractional thulium, erbium-doped yttrium aluminum garnet (Er:YAG), and Er: Glass lasers in AGA [Figure 1]. This article's goal is to provide dermatologists and patients with an overview of the latest developments in laser technology through an analysis of relevant clinical studies and details about each laser mechanism, safety, and efficacy in the treatment of AGA.

LASER APPROACHES FOR AGA

Low-level laser therapy (LLLT)

LLLT (650–1200 nm), also known as photobiomodulation, is the oldest and only FDA-approved device for treating AGA (2007). Many review articles have discussed its efficacy, mechanism, and clinical evidence.[10-12] Several underlying mechanisms support its efficacy. The primary mechanism involves the absorption of low-level light by skin chromophores, leading to nitric oxide (NO) production and the modulation of reactive oxygen species (ROS). This triggers the release of cytokines, which have anti-inflammatory effects and activate the Wnt10b/β-catenin pathway, promoting hair growth by stimulating signaling pathways within HF cells.[13] Moreover, LLLT enhances the function of dermal papilla cells, which play a crucial role in HF development. This therapy upregulates proteins involved in transcription, lipid homeostasis, and extracellular matrix maintenance, thereby promoting hair regrowth and reversing the miniaturization of HFs.[14]

Friedman and Schnoor[15] assessed a 650 nm LLLT device (HANDI-DOME LASER) used every other day for 17 weeks in women aged 18–60 with AGA, reporting a 51% increase in hair counts compared to the control group. Mai-Yi Fan *et al.*[16] conducted a 24-week randomized controlled trial with 100 AGA patients and found that the LLLT-treated side of the scalp showed significantly greater improvements in hair coverage, thickness, and count compared to the sham-treated side, with no serious adverse effects. In a similar vein, Suchonwanit *et al.*[17] also recorded significant increases in hair density and diameter using a helmet-type LLLT device (RAMACAP). In addition, Yoon *et al.*[18] and Kim *et al.*[19] observed substantial increases in hair density and thickness after 16 weeks of treatment with helmet-type and home-use LLLT devices, respectively [Table 1].

However, when LLLT was combined with traditional treatments like minoxidil, the results were mixed. Faghihi *et al.*[20] reported enhanced hair density and patient satisfaction with the combination, while Ferrara *et al.*[21] and Sondagar *et al.*[22] found no significant additional benefit from combining LLLT with minoxidil.

Red light LLLT

Red light laser treatment (630–700 nm) has shown promising results in AGA therapy by strengthening hair, improving blood circulation, modulating oxidative stress, and promoting hair growth factors (GFs).[23] The 675 nm

Figure 1: Lasers used in androgenetic alopecia (AGA) – (a) erbium-doped yttrium aluminum garnet (Er:YAG), (b) fractional thulium, (c) picosecond, (d) Er: glass, (e) low-level laser therapy, (f) 675 nm, and (g) fractional CO_2.

laser is highly effective in targeting collagen due to its selective absorption, minimizing interaction with vascular components and water, making it optimal for directly affecting collagen fibers without significantly impacting other chromophores. Its penetration depth exceeds 1 mm, creating a thermal column that diffuses heat to surrounding areas, thereby enhancing treatment effectiveness. In addition, red light at 660 nm stimulates the anagen phase of HFs, extending this active growth phase and delaying the transition to the catagen phase.[12] Furthermore, near-infrared light promotes cell proliferation and differentiation of stem cells, as indicated by increased expression of KI67, a biomarker of cell proliferation.[17,23]

An *in vivo* study on C57BL/6 mice suggested a mechanism of red light (670 nm) that promotes vasodilation by triggering the release of a vasoactive substance, S-nitrosothiols (RSNO), from the endothelium, which operates in a NO-dependent but endothelial NO synthase-independent manner. This process involves the formation of extracellular vesicles containing RSNO, which exit the endothelium and induce smooth muscle relaxation. This study demonstrated enhanced vesicular trafficking and increased expression of CD63 in endothelial cells followed by exocytosis.[24] In an *ex vivo* study using 650-nm red light, Yang *et al.*[23] noted the promotion of HF proliferation, delayed the anagen-to-catagen transition, and involved processes like leukocyte migration. RNA-sequence revealed the specific gene signatures associated with these effects. Building on this, Sorbellini *et al.*[25] experimented with 675 nm laser efficacy in AGA patients. Results revealed a significant increase in hair shaft density and reduced miniaturization by 60% with no side effects. Further, research by Chandrashekar *et al.*,[26] observed a 17% increase in hair count and density and a 16.61% increase in hair thickness after 14 sessions, indicating improvements in hair growth and quality [Table 1].

Blue light laser

Blue light therapy (BLT) for AGA works through multiple biological pathways. It promotes hair growth by photolytically generating NO from nitrosated proteins, which enhances vasodilation and prolongs the anagen phase of HFs. BLT activates photoreceptors Opsin 2/rhodopsin (OPN2) and OPN3 (panopsin), expressed in human skin and anagen follicles, particularly through blue light at 453 nm, which has been shown to stimulate hair growth. In addition, BLT regulates melanogenesis by activating OPN3 and the tyrosinase-related protein complex involved in melanin synthesis and transfer to keratinocytes.[27,28] It also interacts with proteins like cytochrome C oxidase, which acts as a light acceptor, influencing enzymes and proteins such as nicotinamide adenine dinucleotide phosphate hydrogen (NADPH) oxidase and calcium channels, thereby activating secondary messengers such as NO, ROS, cyclic adenosine monophosphate (cAMP), adenosine triphosphate (ATP), and calcium ions. These combined mechanisms support HF regeneration and growth.[28-32]

Lodi *et al.*[33] tested the efficacy of blue light-emitting diode (LED) light at 417 nm in AGA patients, observing an increase in hair density and shaft width in 90% of participants after 10 weeks, with 80% showing photographic improvement. No serious adverse events were reported, although two patients experienced hair darkening, potentially due to melanin stimulation by blue light. In addition, a study confirms that blue light at 453 nm induces the accumulation of cryptochrome 1 (CRY1) in human keratinocytes and HFs, where CRY1 is highly expressed in the anagen phase. Silencing CRY1 promotes catagen while stimulating it prolongs anagen, suggesting that CRY1 mediates blue light's positive effects on hair growth.[27]

Combination treatment-LLLT with microneedling (MN), platelet-rich plasma (PRP) , Growth factors (GFs), and exosomes

The primary limitation of LLLT for hair growth is its insufficient light penetration into the scalp. To address this, the concept of precision LLLT has been introduced, combining low-intensity lasers or LEDs with microneedling (MN). LLLT, through photobiomodulation, stimulates cellular activity, promotes healing, and activates the metabolism of HFs for regeneration and hair growth. While, MN creates micro punctures in the skin, initiating the wound healing process. This process releases factors such as Wnt3a, Wnt10b, and epidermal GFs, which activate HFs. The combined approach, often called "microneedle patch," enhances hair regrowth by stimulating neocollagenesis, neovascularization, and GF release.[34]

PRP is an established treatment for hair growth as a standalone therapy or combined with other treatments. Numerous studies support its efficacy. PRP treatment involves an autologous preparation of plasma with highly concentrated platelets. This plasma contains over 20 GFs crucial for hair regrowth and enhances the biological processes involved in HF regeneration. A retrospective case-series study evaluated the combined use of autologous non-activated PRP, LLLT (423–640 nm) and MN.[35] Eitta *et al.*[36] combined LLLT (650–670 nm) with PRP and evaluated the trichogenic effects in AGA patients. The results showed significant improvements in hair diameter, vellus hair, terminal hair, and hair density after the initial three months of treatment. Although these improvements diminished somewhat after discontinuing the treatment, the results remained better than baseline levels.

Kittigul *et al.*[37] investigated the precision LLLT efficacy in C57BL/6 mice using different LED wavelengths – red (629 nm), green (513 nm), and blue (465 nm) – along with MN

Table 1: Recent research summary of LLLT and 675 nm lasers in AGA.

Laser type and treatment	Study design	Treatment components	No. of sessions	Adverse events	Results	References
Dome Laser Unit (650 nm)	44 healthy female volunteers, 18–60 years, randomized to active or placebo groups.	272 diode lasers, 5 mW each, 650 nm wavelength, 30 min/treatment, every other day for 17 weeks (60 treatments).	60 sessions, every other day	No reported side effects or adverse events.	51% increase in terminal hair counts in the laser group compared to the sham group.	Friedman and Schnoor, 2017[15]
Helmet-type LLLT device (660 nm LED and 650 nm Laser)	24-week, sham-controlled trial in patients 25–60 years with AGA.	27 LEDs (660 nm)+27 laser diodes (650 nm), 10 min for the anterior, middle, and posterior scalp (30 min total), 3 times per week for 24 weeks	72 sessions, 3 times per week	29.3% reported adverse events: eczema (4%), pruritus (3%), and acne (1%); resolved within 2 weeks	Higher hair coverage and thickness increase on the LLLT-treated side compared to the sham-treated side after 24 weeks.	Fan *et al.*, 2018[16]
LLLT device (785 nm)+ Minoxidil	17–45 years old patients, randomized to LLLT+minoxidil or minoxidil+sham comb	785 nm wavelength, 10–50 mW power, 20 min/treatment, 2–3 times per week for 24 weeks.	48–72 sessions, 2–3 times per week	No significant differences in side effects between groups; mild headache, itching, and burning were reported in both groups.	Significant increase in hair count and hair diameter in the LLLT+minoxidil group compared to controls.	Faghihi *et al.*, 2018[20]
Cap-shaped LLLT device (660 nm)	24-week, randomized, double-blind, sham-controlled trial; 40 subjects (20 men, 20 women).	99 LEDs, 5 mW each, 660 nm wavelength, 12 min/treatment, twice per day for 6 months.	144 sessions, twice per day	No serious adverse events. 1 female subject reported increased hair shedding, which was resolved within 6 weeks. Mild scalp itching in 3 subjects.	Significant increase in hair density and hair diameter in the laser group compared to the sham group at week 24.	Suchonwanit *et al.*, 2019[17]
LLLT helmet (655 nm)	60 participants with AGA, randomized to active or sham groups.	Mean output power of 2.36 mW/cm², 25 min/treatment, every other day for 16 weeks.	56 sessions, every other day	No adverse events or side effects occurred.	Significant increase in hair density (41.90 hairs/cm²) and hair thickness (7.50 μm) in the active group compared to the sham group.	Yoon *et al.*, 2020[18]
LLLT device (660 nm)	48 healthy volunteers with AGA, were randomized to active or sham device groups.	660 nm wavelength, 27 min/treatment, 3 times per week for 16 weeks.	48 sessions, 3 times per week	2 subjects in the test group experienced itching; 1 subject reported eye disorder and another felt dizzy.	Significant increase in hair density (18.34%) and hair thickness (16.29%) in the test group compared to baseline.	Kim *et al.*, 2020[19]

(Contd...)

Table 1: *(Continued).*

Laser type and treatment	Study design	Treatment components	No. of sessions	Adverse events	Results	References
Cap-shaped LLLT device (660 nm LED)	21 men with AGA, randomized to LLLT on one side and minoxidil-only on the other.	660 nm wavelength, 99 LEDs, 5 mW each, 12 min/treatment, twice per day for 6 months.	144 sessions, twice per day	No adverse events were recorded.	Significant increase in total hairs on both sides; no statistically significant differences between the LLLT and minoxidil-only sides.	Ferrara *et al*., 2021[21]
Laser comb (655±10 nm)	Group A: LLLT therapy+minoxidil; Group B: Minoxidil only. 54 patients (26 in Group A, 28 in Group B). Evaluated monthly for 4 months.	Multiple passes for 11 min/session, twice per week for 12 weeks.	24 sessions, twice per week	No significant adverse effects. Headache, mild erythema and itching.	Highest improvement in hair density in Grade III AGA in LLLT+minoxidil group; Mean increase in hair density: Group A=34.5 hairs/cm^2, Group B=24.21 hairs/cm^2.	Sondagar *et al*., 2023[22]
650 nm Red Light Laser	*Ex vivo* HF culture study. HFs are divided into 3 groups, with exposure times: 5, 10, and 0 min (control)	650 nm wavelength, 0.8 J/cm^2 (exposure time: 5 min) and 1.6 J/cm^2 (exposure time: 10 min).	-	None	Promoted proliferation of human HFs, the delayed transition from anagen to catagen identified gene signatures	Yang *et al*., 2021[23]
675 nm Red Light Laser	17 patients with mild-to-moderate AGA treated twice a week, one single pass with an optional second pass on thinned areas	Fluence 12.5 mJ/DOT, spacing 1500 micron, cooling temperature 15°C, 20 min per session	10 sessions, 2 per week	No side effects detected	Significant increase in hair count and density over 5 months; reduction in hair miniaturization by 60%	Sorbellini *et al*., 2023[25]
675 nm Red Light Laser	Clinical study with 20 Indian patients	0.7 mm width (DOT area), 1W, dwell time 100 ms, Stack 1, spacing of 1000 µm and cooling temperature 15°C.	14 sessions. Twice a week 8 sessions; Once in a week 4 sessions; Once in 2 weeks 2 sessions	None	Increased hair count and density (~17%), increased hair mean thickness (~16.61%), improvement across treated areas	Chandrashekar *et al*., 2024[26]
Blue LED Light Therapy (417±10 nm)	Prospective, single-arm interventional study	Fluence: 120 J/cm^2, Power: 60 mW/cm^2 ±20%	20 sessions (twice a week for 10 weeks)	Darkening of hair in 2 patients (no serious adverse events)	Increase in hair density and hair shaft width in 90% of patients; photographic improvement in 80%	Lodi *et al*., 2021[33]

(Contd...)

Table 1: *(Continued).*

Laser type and treatment	Study design	Treatment components	No. of sessions	Adverse events	Results	References
LLLT+ANA-PRP+ Microneedling	Retrospective study	Red light (640 nm, 1-6 mm penetration), Blue light (423 nm, 1 mm penetration), Micro-needling: 1.0 mm sterile micro-needling stamp	48 sessions over 6 months (twice per week) 3 sessions, repeated every 15 days over 6 months	No major side effects	Synergistic effect improved hair growth	Gentile *et al*., 2020[35]
PRP Injections +LLLT	Open-label, interventional study	iGROW1 helmet: 21 Laser Diodes+30 LEDs, 655 nm red laser (output<5mW CW), LED wavelength 650–670 nm	4 PRP sessions (3 weeks apart)+LLLT (25 min, 3 times/week for 3 months)	No major side effects were reported	Significant improvement in hair density, terminal/vellus hair ratio, and hair diameter after 3 months.	Eitta *et al*., 2022[36]
LED MN patch +red (629 nm), Green (513 nm), Blue (465 nm) Light	Animal study (mice) - Comparative study Control group- LED irradiation alone	Red, green, and blue light with an energy dose of 0.2 J/cm², applied once daily for 28 days	28 sessions (once daily for 28 days)	No serious adverse events were observed	Significant hair growth with green light, moderate with red, and lowest with blue. MN patch enhanced faster anagen entry and increased follicle count in all groups.	Kittigul *et al*., 2023[37]
MN with LLLT and GFs	A multicentric (Italy and Korea), retrospective case-series observational study	The device contains LLLT emission (red light 640 nm; blue light 423 nm) and sterile infiltration (0.22 _m) by MN containing several GFs	-	-	The combination treatment proved effective in patients whose hair growth had plateaued after using Finasteride® and in those who did not see significant results from the drug	Gentile and Ki, 2022[38]
LLLT+ MN+GFs	Open-label case-series observational clinical study	Hairgen Booster®-MN+LLLT (red light 640 nm; blue light 423 nm)+GFs	40 sessions, twice per week for 20 weeks	-	Combination treatment effective in mild hair loss and telogen effluvium related to COVID-19	Gentile, 2022[39]
Right Frontal Lobe-Green LED Light (513 nm) +MN Patch Left Frontal Lobe Red LED light (629 nm)+ MN Patch	Open-label, interventional, split scalp study	Energy dose: 0.2 J/cm², MN length: 900 µm, 105 needles/cm²	12 sessions (weekly for 3 months, 20 min each)	No serious adverse events	Dermatologist evaluation and Patient satisfaction score was greater on the combination of Green light with MN patches than red light treatment.	Rattanapirat and Meephansan, 2024[40]

(Contd...)

Table 1: *(Continued).*

Laser type and treatment	Study design	Treatment components	No. of sessions	Adverse events	Results	References
LLLT+ Microneedling (1.5 mm) +Clobetasol Propionate 0.05%	Case series (patients with AGA)	LLLT: 25 minutes/session, microneedling with 1.5 mm needles applied in longitudinal, vertical, and diagonal directions until mild erythema	Monthly sessions for 6 months.	No side effects reported	Combination treatment resulted in effective hair regrowth.	Sukarnadi and Hidayat, 2023[41]
MNs+ HMNs (HNP-decorated MNs)+ exosomes of hAMSC +Yellow Light (1900 K)	Experimental study (BALB/c and C57BL/6 mice)	HMNs with HNP, exosomes of hAMSCs, homemade 1900 K yellow light therapy for inflammation reduction and HF stimulation	Daily treatments for up to12 days	No adverse effects were observed	Hair regrowth observed within 7 days in groups with 1900 K light. Improved hair density, hair shaft length, and significant angiogenesis in the HMNs+ exosomes group.	Hong *et al.*, 2021[42]

AGA: Androgenetic alopecia, ANA: Autologous non-activated, hAMSC: Human amniotic mesenchymal stem cells, DOT: Dermal optical thermolysis, HNP: Hair nanoparticles, MN: Microneedling, LLLT: Low-level laser therapy, LED: Light-emitting diode, HF: Hair follicle, HMN: Hollow microneedle, CW: Continuous wave, GFs: Growth factors, BALB/c: Bagg Albino C mice, C57BL/6: C57 Black 6 mice, PRP: Platelet-Rich Plasma

for 28 days. The combination treatment resulted in faster and greater hair growth than LED alone, with green light showing the most significant improvement. Histopathological analysis revealed increased HFs, collagen production, angiogenesis, and immune cell infiltration in treated areas. The green-light LED microneedle patch was most effective at triggering the telogen-to-anagen hair growth transition, with no serious side effects observed, suggesting its potential for treating AGA.

Building on this research, multiple studies investigated the efficacy of MN, LT (red light at 640 nm and blue light at 423 nm), and GFs.[38,39,41] Rattanapirat and Meephansan[40] conducted a pilot study, testing the safety and efficacy of green LED light (513 nm) and red light (629 nm) in combination with MN for AGA patients. All these approaches increased hair thickness, new hairs were noticed and significant scalp coverage was noted with no side effects.

Recent advancement of combined hair regrowth treatment involved MN patches decorated with hair nanoparticles and exosomes from human amniotic mesenchymal stem cells (hAMSCs), along with low-color-temperature yellow light (1900 K). The MNs facilitated drug delivery by penetrating the scalp, allowing hAMSC exosomes to activate HF stem cells and trigger the transition from telogen to anagen. Simultaneously, the yellow light alleviated HF inflammation, further promoting hair regrowth. Animal studies demonstrated significant hair regrowth within 7 days using this synergistic approach, with no adverse effects, highlighting its potential for clinical application.[42]

Combination therapies such as these offer a beneficial option for AGA patients who are non-responders to FDA-approved drugs or achieve moderate results from other treatments. However, to establish standardized treatment protocols, prospective multicenter studies are necessary.

Fractional lasers

Fractional lasers deliver laser energy in a fractionated manner, targeting specific areas of the skin while sparing surrounding tissue. This technique enhances skin rejuvenation and treats various skin conditions, including AGA. Fractional lasers are categorized into two main types:

- Ablative Fractional Lasers: These lasers remove the outer layer of the skin, promoting significant skin resurfacing and collagen remodeling. Ablative lasers effectively treat scarring, wrinkles, and skin laxity but may involve longer recovery times due to their invasive nature.[43]
- Non-Ablative Fractional Lasers: These lasers penetrate the skin without damaging the outer layer, stimulating collagen production and tightening skin with minimal downtime. Non-ablative lasers are commonly used for skin rejuvenation, addressing pigmentation, and vascular changes.[43]

Table 2: Study details on fractional CO_2 laser in AGA treatment.

Laser type and treatment	Study design	Laser parameters	No. of sessions	Adverse events	Results	References
Fractional CO_2 Laser+Hair Growth Factors	Randomized Half-Split Study. Laser on one side and hair growth factors on both sides	12–18 mJ/spot, 361 spots/cm², 1 pulse, 40% density	6 sessions, 2-week intervals	Transient hair shedding (*n*=1), slight pain, mild erythema (*n*=27), edema (*n*=7), pruritus (*n*=8), dryness (*n*=3), seborrheic dermatitis (*n*=2), dandruff (*n*=7)	Combined treatment showed superior improvement in hair density and patient satisfaction compared to growth factors alone.	Huang *et al*., 2017[44]
Fractional CO_2 Laser+Topical Minoxidil	Comparative Study. 45 men with AGA were divided into 3 groups: combined group (laser+minoxidil), laser-only group, minoxidil-only group	DOT fractional scanning, 1 pulse, 15 mm spot size, 5 W power, 500 µs dwell time, smart stack 3, pulse mode, 700 µm spacing, 8.7% density, 4.68 J/cm², 51.6 mJ pulse energy	6 sessions, 2-week intervals	44% no side effects; mild erythema (33%), itching (16%), post-inflammatory hyperpigmentation (7%)	Significant improvement in hair count and thickness, especially in the combined group; minoxidil alone showed less improvement	Salah *et al*., 2020[45]
Fractional CO_2 Laser+Topical Minoxidil	Prospective Randomized Controlled Trial Group A: minoxidil Group B- minoxidil plus fractional CO_2 laser	6W, Dot mode, Spacing 550 µm, Dwell time 400 ms, 10/10, Size 100%, Fluence 0.3 J/cm², Density 11.9%, Energy/dot 2.4 mJ	Group A: 12 weeks 4 sessions with 2-week intervals+ Minoxidil after each session	No serious adverse effects were reported	Significant improvement in both groups; combined therapy superior to minoxidil alone	Rashed *et al*., 2022[46]
Fractional CO_2 Laser	Experimental Study in Mouse Model	10, 15, and 20 mJ/spot; 5%, 10%, and 15% coverage	Single session	Not applicable (animal study)	Effective at 15 mJ/spot; increased macrophages, improved hair regrowth in a mouse model.	Hasegawa *et al*., 2022[47]
Fractional CO_2 Laser+PRP +Saline	Split-Scalp Prospective Interventional Study area 1: PRP injection, area 2: fractional CO_2 laser irradiation, area 3: combined fractional CO_2 laser followed by topical PRP application, and area 4: intradermal saline injection as control	Spot size 50 mm, 12 mJ/spot, 361 spots/cm²; PRP: Prepared by double spin method; Calcium gluconate used for activation	Total 8 sessions. every 2 weeks for 4 sessions, then monthly for 4 months	Not specified	PRP+fractional CO_2 laser showed superior results compared to single treatments or saline in patients with FPHL	Tawfik *et al*., 2024[48]

(Contd...)

Table 2: *(Continued).*

Laser type and treatment	Study design	Laser parameters	No. of sessions	Adverse events	Results	References
Fractional CO_2 Laser+PRP	Pilot Study	12 mJ, 800 spots/cm² (low energy) versus 22 mJ, 400 spots/cm² (high energy); PRP: Prepared by double spin method; Calcium gluconate used for activation	10 sessions of lasers followed by PRP at 2-week intervals.	Minor, well-tolerated.	Higher pulse energy (22 mJ) resulted in significantly better hair density improvement compared to lower energy (12 mJ)	Hanthavichai *et al.*, 2022[49]

AGA: Androgenetic alopecia, PRP: Platelet-rich plasma, FPHL: Female pattern hair loss, CO_2: Carbon dioxide, DOT: Dermal optical thermolysis

Fractional ablative CO_2

The fractional CO_2 laser, widely recognized for its skin rejuvenation properties, also shows potential in treating AGA by stimulating HFs through its wound-healing effects, as observed in murine models.[50] This laser creates microscopic thermal injury zones that can trigger the transition from the telogen to anagen phase, promoting new hair growth.[44] The mechanism underlying this effect, demonstrated in C57BL/6 mice, involves creating an inflammatory microenvironment, promoting VEGF-mediated angiogenesis, and activating the Wnt10b signaling pathway, all of which contribute to hair regrowth.[51] More recently, Hasegawa *et al.*[47] demonstrated that CO_2 laser irradiation recruits Ccr2-positive macrophages, further supporting hair regrowth in a mouse alopecia model. These studies collectively enhance the understanding of the cellular and molecular mechanisms behind hair cycle initiation.

Clinical studies have consistently demonstrated the efficacy of fractional CO_2 lasers in treating AGA, particularly when used as a combination therapy. Rashed *et al.*[46] and Huang *et al.*[44] reported significant improvements in hair density, count, and thickness when fractional CO_2 laser treatments were combined with topical minoxidil or hair GFs. Salah *et al.*[45] further supported these findings, noting that patients treated with a combination of fractional CO_2 laser and minoxidil showed superior improvements in hair number and thickness in male AGA compared to those receiving monotherapy. Furthermore, Tawfik *et al.*[48] found that combining CO_2 laser therapy with PRP produced remarkable results in treating female pattern hair loss (FPHL), significantly improving hair density and hair quality, and effects were well-tolerated and long-lasting [Table 2].

Across these studies, fractional CO_2 laser therapy was consistently reported to be safe, with no serious adverse effects. The minimally invasive nature of the procedure, coupled with its durable results, positions the fractional CO_2 laser as an adjunctive treatment for AGA.

Fractional Erbium YAG: 2940 nm laser

The 2940-nm Er:YAG laser has garnered attention as a potential therapeutic tool for hair restoration and was initially introduced in 1995 for hair restoration. This laser promotes hair regrowth through several mechanisms. One of the primary pathways involved is the Wnt/β-catenin signaling pathway, which plays a critical role in the transition of HFs from the telogen (resting) phase to the anagen (growth) phase. The murine model study by Ke *et al.*,[52] demonstrated that Er:YAG laser treatment significantly upregulates the expression of Wnt 10b and β-catenin, leading to accelerated HF cycling and increased hair growth. In addition, histological analyses have revealed an increase in HF density and an improved anagen-to-telogen ratio, further supporting the laser's role in enhancing hair growth dynamics.[52,53]

Moreover, the Er:YAG laser improves transdermal drug delivery by selectively ablating the stratum corneum, the main barrier to drug absorption. This enhances the penetration of topical agents like minoxidil through mechanisms such as skin barrier ablation, optical breakdown through photomechanical waves, and photothermal effects, creating temporary pathways for better drug absorption, crucial for treating AGA.[54]

Clinical studies have consistently demonstrated the efficacy of the Er:YAG laser in treating AGA, both as a monotherapy and in combination with other therapies [Table 3]. In a study by Mokhtari *et al.*,[54] male patients with moderate-to-severe AGA showed significantly enhanced hair regrowth when treated with a combination of 2940-nm ablative fractional Er laser and 5% minoxidil, compared to those who received minoxidil alone. This improvement is attributed to the laser's ability to stimulate HFs and improve drug delivery. Ahn[55] further corroborated these findings and reported effective hair regrowth with minimal side effects in patients treated with the Er:YAG laser and a hair growth-promoting solution through JetPeel™, particularly in the frontal and vertex regions.

Table 3: Study details on Er:YAG laser (2940 nm) in AGA treatment.

Laser type and treatment	Study design	Laser parameters	No. of sessions	Adverse events	Results	References
Ablative Fractional Er: Laser+Hair Growth Solution	Case Study	Approx. 0.05 J/cm²	1+12 (Hair Growth Solution)	No significant side effects; mild erythema	Successful hair growth promotion in the treated areas	Ahn, 2021[55]
2940-nm Ablative Fractional Er Laser+Minoxidil	Randomized Controlled Trial. Two groups: intervention (laser+minoxidil) and control (minoxidil)	Pulse energy 1500 mJ/cm², 8×8 mm, Frequency 3 Hz, Pulse mode: short; Minoxidil: 5% topical solution	6 (Laser)+6 months (Minoxidil)	Minoxidil only: itching, seborrheic dermatitis. Laser+minoxidil: hair shaft damage, erythema, contact dermatitis	Significant improvement in both groups; laser+minoxidil group showed a higher dermoscopy score than minoxidil alone	Mokhtari *et al.*, 2023[54]
Non-Ablative ErLaser+PRP	Pilot Study	SMOOTH™ mode, 7 mm spot size, 7.00 J/cm² pulse fluence, 3.3 Hz, cross-hatched pattern, 450 J total energy	8 sessions, 2-week intervals	No adverse effects; pain level 2 on VAS scale (0–10)	AGA grades decreased in 69% of patients; 93% showed improvement in hair quality (better or much better)	Day *et al.*, 2021[56]
Non-Ablative Er Laser+PRP	Case Report-Single patient with combination therapy (Er laser in SMOOTH mode+PRP injection)	ErLaser: 2940 nm, SMOOTH™ mode, 7 mm spot size, 8.5 J/cm² pulse fluence, 3.3 Hz, cross-hatched pattern, 8 passes; PRP injections	3 sessions, 1 month apart	No adverse effects reported	Significant restoration of hair density; maintenance of results several months after therapy	Maksimov, 2021[57]
2940-nm Er Laser	Case Report- Single patient	Er Laser: 2940 nm, Pulse fluence 2 J/cm², Frequency 1.6 Hz, R11 handpiece	6 sessions, 2-week intervals	No laser-related side effects or pain reported	26–50% improvement in hair growth; increased hair density and count; improved patient satisfaction and trichoscopic measurements	Dekeyser, 2021[58]

AGA: Androgenetic alopecia, PRP: Platelet rich plasma, Er:YAG: Erbium-doped yttrium aluminum garnet laser, VAS: Visual analogue scale

The efficacy of non-ablative Er:YAG laser therapy has also been explored. Day *et al.*[56] demonstrated that non-ablative Er laser, used as a monotherapy or in combination with PRP and minoxidil, significantly reduced AGA grades and improved hair quality in 93% of patients. This treatment was associated with high patient satisfaction and minimal discomfort. Similarly, Maksimov[57] reported substantial hair density restoration in a grade-3 AGA patient following a combination of non-ablative Er:YAG laser therapy and PRP injections, with sustained results and no adverse effects. In FPHL, Dekeyser[58] found that six sessions of ER: 2940 nm laser treatment effectively stabilized hair loss and increased hair density, with no reported side effects.

These findings collectively suggest that the Er:YAG laser, both in its ablative and non-ablative forms, whether used alone or in combination with other treatments, is a safe and effective option for improving hair regrowth and quality in AGA patients.

Fractional non-ablative 1550 and 1540 nm Er: glass lasers

The Er: Glass laser enhances cellular signaling and microenvironmental conditions conducive to HF activation and growth. This laser stimulates hair regrowth by enhancing hair density and shaft diameter, primarily through the modulation of GFs such as fibroblast growth factor, epidermal growth factor, insulin-like growth factor, and VEGF, which are crucial for wound healing and hair cycling.[59] In addition, the laser improves transdermal drug delivery, which elevates VEGF and prostaglandin E2 levels, helping to increase blood flow to HFs and further promoting hair growth.[60]

Kim *et al*. (2011)[61] demonstrated that a 1550-nm fractional Er laser could stimulate hair growth in both a murine model and a pilot human study, with improvements observed in hair density and growth rate. In addition, Lee *et al*.[62] showed significant increases in hair density and thickness in South Korean

Table 4: Studies on fractional Er: glass laser in the treatment of AGA.

Laser type and treatment	Study design	Laser parameters	No. of sessions	Adverse events	Results	References
1550-nm Fractional Er Laser	Pilot Study- Half-split study; right side treated with laser, left side untreated (control)	Energy 5 mJ, Total density 300 spots/cm²; Various energy levels and densities tested in animal model	5 sessions, 2-week intervals	Hair shaft breakage, mild erythema (*n*=11), pruritus (*n*=4), dryness (*n*=10), dandruff (*n*=7), transient shedding	Increased hair density and growth rate; no significant changes in hair caliber; density decreased to baseline at 4 months	Kim *et al*., 2011[61]
1550-nm Fractional Er Laser	Clinical Trial- 28 FPHL patients	5–10 mm tip, 6 mJ pulse energy, 800 spot/cm² density, static mode, 1 pass	10 sessions, 2-week intervals	Mild pruritus in 7.4% of patients; resolved in 2 h	Significant increase in hair density and thickness; improvement observed in 87.5% of patients	Lee *et al*., 2011[62]
Non-Ablative 1550-nm Er Laser+Topical Finasteride+Growth Factors	Case Series- 4 patients with FPHL/MPHL. 1550 nm laser+Topical Finasteride: 0.05%+Growth factors: 1% Copper peptide, BFGF, IGF, VEGF	7 mJ, 3–9% coverage, 120 mt/cm² density, 8 passes		No significant side effects were observed	Improvement in hair regrowth and density in all four patients; positive response observed	Bertin *et al*., 2018[63]
Er Glass (1550 nm) +5% Minoxidil	30 men with AGA; split-scalp treatment with laser+minoxidil on one side and minoxidil alone on the other side	6 mJ energy, 300 spots/cm² density, 7 mm probe, 10% overlapping area, 1 pass	12 sessions, 2-week intervals	Tolerable pain, erythema (*n*=6), itchiness (*n*=4), scaling (*n*=2)	Significant improvement in hair density and diameter; combination therapy superior to monotherapy	Suchonwanit *et al*., 2019[60]
1540-nm Fractional Er Laser	Interventional Therapeutic Study- 51 AGA patients	7 mm tip, 6 mJ pulse energy, 1 Hz frequency; One pass per session	10 sessions, 2-week intervals	Mild erosion (*n*=1), mild erythema (*n*=2), burning sensation in treated area (*n*=2)	68% of women showed improvement; 45% of men showed improvement; some patients stabilized, a few worsened	Alhattab *et al*., 2020[64]

AGA: Androgenetic alopecia, FPHL: Female pattern hair loss, MPHL: Male pattern hair loss, BFGF: Basic fibroblast growth factor, IGF: Insulin-like growth factor, VEGF: Vascular endothelial growth factor

Table 5: Studies on fractional picosecond lasers in AGA.

Laser type and treatment	Study design	Laser parameters	No. of sessions	Adverse events	Results	References
Fractional Picosecond Laser	Pilot Study	1064-nm, Spot size 8 mm, Fluence 0.06 J/cm², Frequency 10 Hz, 3–4 passes	3, 4-week intervals, with a follow-up 4 weeks post-procedure	Minimal pain (1–2/10) resolved within 15–30 min, few petechiae, no local adverse reactions, no hair shaft breakage, no pruritus, dryness, or dandruff	Significant increase in expert panel assessment scores and patient satisfaction; minimal petechiae observed	Lueangarun and Tempark, 2024[65]
Fractional Picosecond Laser+ Exosomes	Case Study	1064-nm, Spot size 8 mm, Fluence 0.06–0.1 J/cm², Frequency 10 Hz, 3–4 passes	4 (Exosomes+ Laser)	No significant adverse events were reported	Clinical improvement in hair regrowth and repigmentation of white hair patches was observed; dermoscopic evaluation showed proximal black coloring	Lueangarun *et al.*, 2024[66]

AGA: Androgenetic alopecia

Table 6: Research summary of fractional thulium laser in AGA treatment.

Laser type and treatment	Study design	Laser parameters	No. of sessions	Adverse events	Results	References
1927 nm Fractionated Thulium Laser+PDRN Injections	Clinical study with 16 Korean patients. Group 1: 8 received laser+PDRN Group 2: 8 received mesotherapy+PDRN	5W, 6 mJ, static mode, 100–140 pulses. 2 ml PDRN injected	12 sessions (weekly intervals)	Group 1: Transient redness, mild itching, desquamation Group 2: Pain, bleeding, oozing, itching, desquamation	Greater improvement in hair thickness with laser+PDRN, but no significant difference in hair counts.	Cho, 2016[67]
1927 nm Fractionated Thulium Laser+Growth Factor Serum	Split-scalp study with 10 PHL patients	5W, 4–6 mJ, static mode, 100–140 pulses	12 sessions (weekly intervals)	Mild itching in 3 patients	Significant increase in hair density and thickness, enhanced efficacy with post-laser growth factor solution	Cho *et al.*, 2018[68]
1927 nm Fractional Thulium-doped Fiber Laser+PRP	Pre- and post-treatment study with 9 men	3–5 W, 5–10 mJ/spot, 0.5–20 ms, 3–5 passes	3 sessions laser followed by PRP injections at 1 month interval	1 serious adverse effect; transient erythema and mild pain. VAS for pain: 0.8 (laser) and 4.2 (PRP injections).	9.7% increase in total hair density; 28.1% increase in terminal hair density; GPA improvement in 67–89%	Brownell *et al.*, 2019[69]
1927 nm Fractional Laser	Clinical study with 10 subjects with AGA	1 W, 1 mJ, dynamic mode, 4 passes	Group A: 12 (weekly); Group B: 6 (2-weekly); Group C: 3 (4-weekly)	Group A: 12 (weekly); Group B: 6 (2-weekly); Group C: 3 (4-weekly)	Increased hair density, maximum effect at 12 weeks, patient satisfaction lasting until 6 months	Taub *et al.*, 2022[70]

AGA: Androgenetic alopecia, PRP: Platelet-rich plasma, VAS: Visual analog scale, PDRN: polydeoxyribonucleotide, PHL: Pattern hair loss, GPA: Global photographic assessment women with FPHL after a 5-month course of 1550-nm Er laser treatments. Bertin *et al.*[63] reported positive outcomes in four patients treated with a 1550-nm Er laser followed by topical finasteride and GFs, showing enhanced hair regrowth and density without significant side effects. Suchonwanit *et al.*[60] found that combining 1550-nm Er laser therapy with topical 5% minoxidil significantly improved hair density and diameter compared to minoxidil alone in a 24-week study involving 30 men. Finally, Alhattab *et al.*[64] reported that the 1540-nm fractional Er laser effectively improved hair density and thickness in patients with AGA over 5 months [Table 4].

Collectively, studies highlight the potential of Er: lasers as a promising treatment for AGA, with notable improvements in hair regrowth and minimal adverse effects.

Fractional non-ablative pico: 1064-nm

Picosecond lasers stimulate hair growth by creating tiny, non-thermal micro-injuries in the scalp through Laser-Induced Optical Breakdown, triggering a wound healing response that releases GFs and activates HF stem cells. This process helps the transition of HFs from the resting phase to the growth phase, promoting hair regrowth. Furthermore, pico laser activates the Wnt/β-catenin signaling pathway, which is crucial for sustaining the hair growth cycle.[65,66]

Lueangarun and Tempark[65] conducted a pilot study with five male participants using a 1064-nm fractional picosecond laser (FPL), demonstrating significant improvements in hair regrowth and patient satisfaction. The study employed standardized laser parameters and showed clinical and dermoscopic improvements with minimal adverse effects. In continuation, Lueangarun *et al.*[66] further explored the combined use of FPL and exosome therapy in a case study involving a patient with both AGA and poliosis circumscripta [Table 5]. The results showed noticeable hair regrowth and repigmentation of white hair patches, suggesting that combining FPL with exosomes could offer a new treatment avenue for both hair loss and pigmentation issues.

Fractional non-ablative thulium: 1927 nm

The fractional laser induces micro-injuries in the scalp, triggering a wound-healing response that stimulates stem cell proliferation and enhances the anagen phase of HFs, thereby promoting hair regrowth.[43,71] This treatment also disrupts the stratum corneum, improving transdermal absorption of topical GFs and medications like minoxidil, directly targeting the hair roots.[43]

Clinical evidence supports the use of thulium lasers in treating AGA and pattern hair loss (PHL). Taub *et al.*[70] and Cho *et al.*[67] demonstrated that a 1927 nm fractional laser, combined with a GF solution, effectively increased hair density and diameter with minimal side effects in patients with AGA and PHL patients, respectively. Cho[67] showed that combining thulium laser with polydeoxyribonucleotide injections led to significant improvements in hair thickness and density. Finally, Brownell *et al.*[69] reported that thulium laser with PRP therapy resulted in substantial increases in hair density and mass index in male AGA patients, with few side effects. The research studies on thulium lasers in AGA treatment are summarized in Table 6.

CONCLUSION

Laser therapy is becoming a popular option for treating AGA due to its minimally invasive nature, safety, and effectiveness. It is increasingly combined with treatments such as PRP, MN patch, hair GFs, and, of late, with exosomes to improve results and durability, offering a valuable alternative when conventional treatments fall short or are unsuitable. Despite its advantages, challenges remain, such as the need for improved equipment, optimized settings, and a better understanding of treatment duration. Current research suggests a maximum treatment period of up to 6 months, but more high-quality clinical trials are needed to determine the best options for AGA. Future studies should focus on refining laser parameters, comparing different types, evaluating long-term efficacy, and integrating laser-assisted drug delivery to enhance outcomes and address clinical challenges.

Authors' contributions

Dr B. S. Chandrashekar: Contributed to the concepts, study design, manuscript editing and review, and served as the guarantor for the study. Dr Paulomi Vartak: Involved in the concepts, study design, defining the intellectual content and conducting the literature search. Dr Madura C: Assisted with manuscript editing and review. Dr Chaitra Shenoy: Assisted with manuscript editing and review. Dr Abhijna Chandar: Conducted the literature search and data acquisition. Dr Roopa M S: Involved in the literature search, data acquisition, and manuscript preparation. Lakshmi Narayana N: Conducted the literature search and data acquisition.

Ethical approval

Institutional Review Board approval is not required.

Declaration of patient consent

Patient's consent was not required as patients identity is not disclosed or compromised.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

Use of artificial intelligence (AI)-assisted technology for manuscript preparation

The authors confirm that there was no use of artificial intelligence (AI)-assisted technology for assisting in the writing or editing of the manuscript and no images were manipulated using AI.

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How to cite this article: Chandrashekar BS, Vartak P, Madura C, Shenoy C, Chandar A, Roopa MS, *et al*. Laser therapies in androgenetic alopecia: Review and clinical experiences. J Cutan Aesthet Surg. doi: 10.25259/JCAS_73_2024