Table S1. Mechanistic Integration (Part 1).

Therapy	Primary Mechanistic Lever(s)	Molecular / Cellular Effects	Impact on Hair Cycle
Minoxidil (topical/oral)	Angiogenesis, KATP opening	↑ VEGF, ↑ microvascular perfusion, anti-fibrotic signaling	Prolongs anagen, supports miniaturized follicles
Finasteride / Dutasteride	Androgen modulation	↓ DHT → reduces AR-driven miniaturization	Slows follicular regression; maintains anagen
PRP	Wnt activation, angiogenesis	↑ VEGF, PDGF, IGF-1; boosts keratinocyte/DP proliferation	Stimulates telogen→anagen transition
Microneedling	Mechanical stimulation	Wounding → ↑ Wnt, ↑ BMP modulation, macrophage activation	Induces telogen→anagen; enhances drug delivery
LLLT / Photobiomodulation	Mitochondrial activation, Wnt cross-talk	↑ ATP, ↓ oxidative stress; secondary Wnt activation	Supports anagen re-entry; improves follicle metabolism
Exosomes / MSC secretome	Wnt/β-catenin activation, immunomodulation, angiogenesis	miRNA cargo restores DP activity; ↓ inflammation	Promotes telogen→anagen and thickening
ADSCs (adipose-derived stem cells)	Paracrine DP support, angiogenesis	Release trophic factors; improve ECM; ↑ vascularization	Maintains anagen; thickens miniaturized hairs

Supplementary Table S1. Mechanistic Integration (Part 1). Therapies (minoxidil, finasteride/dutasteride, PRP, microneedling, LLLT/photobiomodulation, exosomes/MSC secretome, ADSCs) are mapped to their primary mechanistic levers, proximal molecular/cellular effects, and resulting impacts on the hair cycle. This table summarizes how vascular, metabolic, and paracrine pathways (e.g., angiogenesis, K_ATP opening, Wnt/β-catenin cross-talk, immunomodulation) relate to anagen support or telogen→anagen transition in AGA. Entries reflect representative findings from human and preclinical studies; effect sizes and study quality are detailed in the main text.
Abbreviations: AGA, androgenetic alopecia; PRP, platelet-rich plasma; LLLT, low-level light therapy; MSC, mesenchymal stromal/stem cell; ADSC, adipose-derived stem cell; DP, dermal papilla; ECM, extracellular matrix; ↑/↓, increase/decrease.

Table S2. Mechanistic Integration (Part 2).

Therapy	Primary Mechanistic Lever(s)	Molecular / Cellular Effects	Impact on Hair Cycle
Dermal Papilla / Dermal Sheath Cup cells	Direct DP signaling restoration	Rebuilds DP–matrix axis; restores mesenchymal induction	Supports sustained anagen/partial neogenesis
Wnt activators (e.g., KY19382, PTD-DBM)	Wnt/β-catenin activation	Blocks SFRP1/CXXC5 inhibition; drives HFSC activation	Strong telogen→anagen switch; neogenesis in models
JAK inhibitors (AA context)	Immune niche normalization	↓ IFN-γ / STAT1; restores immune privilege	Prevents premature catagen; allows anagen re-entry
Pro-angiogenic biologics	Angiogenesis	↑ perfusion, ↑ DP survival	Maintains anagen under metabolic stress
Mechanobiology (stretch, pneumatic stimulation)	Mechanical Wnt activation	Activates HF germ, promotes regenerative macrophages	Triggers telogen→anagen
Hair transplantation / FUE	Follicle redistribution, DP integrity	Maintained viability enhanced by PRP/exosomes	Immediate density restoration; not neogenic
3D bioprinting / Organoids	Full follicle neogenesis	DP/DS/keratinocyte tri-culture; ECM scaffolds	Potential de novo folliculogenesis
iPSC-derived follicles / HF cloning	Follicle regeneration	Engineered DP-like and ORS cells forming organ germs	True neogenesis, full cycling in models

Supplementary Table S2. Mechanistic Integration (Part 2). Mechanistic summary of advanced and cell-centric regenerative strategies, including DP/DSC cell therapies, Wnt pathway activators, JAK inhibitors in alopecia areata context, pro-angiogenic biologics, mechanobiology platforms, hair transplantation/FUE, organoids/3D bioprinting, and iPSC-derived follicle/cloning approaches. Each row outlines the dominant mechanistic lever(s), key molecular and cellular effects, and the anticipated impact on hair-cycle dynamics (e.g., sustained anagen, prevention of catagen, or follicular neogenesis), primarily based on preclinical or investigational evidence. Restoration of mesenchymal–epithelial signaling, immune-niche normalization, and developmental programs are integrated across modalities.

Clinical maturity varies among approaches, and durability and safety in humans remain to be established (see main text for study details and regulatory considerations).

Abbreviations: AA, alopecia areata; DP, dermal papilla; DSC, dermal sheath cup; ECM, extracellular matrix; FUE, follicular unit excision; HF, hair follicle; HFSC, hair-follicle stem cell; iPSC, induced pluripotent stem cell; JAK, Janus kinase; ORS, outer root sheath; Wnt, Wingless/β-catenin pathway; SFRP1/CXXC5, Wnt inhibitors, ↑/↓, increase/decrease.