



Advanced liposomal minoxidil serums: Enhanced follicular penetration and synergistic scalp microenvironment support

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Abstract

Topical minoxidil has been the standard first-line topical treatment for androgenetic alopecia (AGA) for decades, and it still disappoints a good number of people who try it. Response is uneven, only a small share of each dose is absorbed through the scalp, and the usual ethanol and propylene glycol vehicle can leave the scalp itchy, dry or inflamed. This review brings together what has been published on these problems and on one proposed answer: carrying minoxidil in phospholipid vesicles (liposomes) in an aqueous, low-solvent serum.

Several independent laboratory and animal studies report higher skin or pilosebaceous deposition of minoxidil from liposomal and related vesicular carriers than from conventional solutions. Those results are encouraging but not uniform, and methods for judging follicular targeting are still debated [8]. We found no controlled human trial of a liposomal minoxidil serum. Separately, oxidative stress and mitochondrial changes in dermal papilla cells give a reasonable biological case for pairing minoxidil with scalp-supportive ingredients.

We discuss how a liposomal serum such as the one being developed on the Lipoedge™ platform by WBCIL (West Bengal Chemical Industries Limited) could be built around these findings, which questions the development programme must answer, and how the story can be told honestly to B2B partners and to consumers.

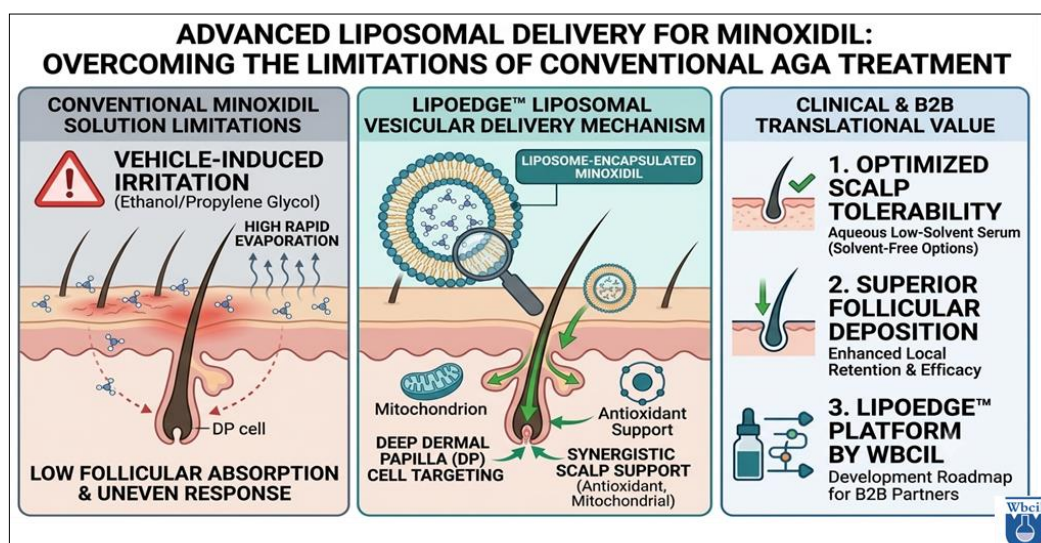
Highlights

- Minoxidil works, but response varies and the vehicle often causes irritation or allergy.
- Follicles can act as a reservoir for particle-based carriers; particle size, massage and sebum all matter.
- Preclinical studies suggest liposomal minoxidil can raise skin and pilosebaceous deposition; human efficacy data are lacking.
- Antioxidant and barrier-supportive ingredients are sensible partners for minoxidil, but their hair-growth benefit in this setting is unproven.
- Lipoedge™ by WBCIL is positioned as the liposomal platform for this format; claims will follow the product's own data.

Keywords: Androgenetic alopecia, minoxidil, liposomes, pilosebaceous unit, oxidative stress, Lipoedge™, WBCIL

Introduction

Graphical Abstract



Why this matter to patients and to the market?

Androgenetic alopecia is the most common cause of progressive hair loss in both sexes, and it tends to show up

earlier and more often than people expect. In Asian populations, reports describe a distinct pattern and a notable share of early-onset cases [14]. Indian dermatologists, in a

published consensus, point out that the emotional toll of AGA is real at every age and stage, and that most patients need treatment for the long haul ^[15].

Long-term use is the commercial and clinical heart of the matter. A product that is applied daily for years has to feel acceptable on the scalp, fit into a normal morning routine, and not make people dread using it. Many of the reason's patients stop or skip minoxidil have more to do with how it feels than with whether it works.

The gap a better format could fill

Minoxidil was first used as a tablet for high blood pressure, and the hair growth seen in those patients led to the topical products we know today ^[1]. In the pivotal 48-week trial in 393 men, 5% minoxidil produced more hair regrowth than 2% minoxidil (about 45% more at week 48) and more than placebo, but it also caused more itching and local irritation ^[16]. So, the stronger option is better for hair and harder on the scalp. That tension is what a carrier-based serum is trying to ease.

This review looks at that idea critically. We separate what independent researchers have actually published about liposomal minoxidil from what remains a design hypothesis for the Lipoedge™ serum that WBCIL is developing, and we try to keep the two from blurring.

Minoxidil in the follicle: how it acts and why results differ

1. What we know about the mechanism

Nobody has a complete explanation of how minoxidil grows hair. The best-supported picture is that it shortens the resting (telogen) phase, nudges follicles into the growth (anagen) phase sooner, may keep them there longer, and helps miniaturised follicles recover some size. The sulfated form of the drug opens potassium channels in smooth muscle, yet convincing proof of the same channels doing the work in the follicle itself is still missing ^[17]. In cultured human dermal papilla cells, minoxidil increased proliferation and reduced apoptosis, with changes in ERK and Akt signalling and in the Bcl-2/Bax balance ^[18]. Cell-culture results are useful clues, not proof of what happens on a living scalp.

2. A pro-drug that needs the right enzyme

Minoxidil itself is inactive. It has to be sulfated inside the follicle, mainly by the enzyme SULT1A1, before it can act. In a study of women with AGA using 5% minoxidil for six months, follicular sulfotransferase activity in plucked hairs predicted who responded, with 93% sensitivity and 83% specificity ^[2].

The practical lesson is a modest one. Getting more drug to the follicle is a sensible goal because that is where the enzyme sits. But a better carrier cannot create enzyme activity that is not there, so nobody should promise that a new vehicle will turn non-responders into responders.

3. Very little reaches the skin's deeper layers or the bloodstream

Roughly 1.4% of minoxidil applied to a healthy scalp is

absorbed, with more absorbed at higher concentrations, with more frequent application, or when the barrier is damaged ^[1]. That figure cuts both ways. It points to inefficient delivery, which is the opportunity. It also means any carrier designed to push more drug into the skin has to be checked for systemic exposure.

The vehicle problem: irritation and allergy

Marketed minoxidil solutions typically rely on ethanol and propylene glycol (PG) to dissolve the drug. Both can bother the skin. A systematic review with individual-participant meta-analysis of patch-test-confirmed allergic contact dermatitis found that minoxidil itself was the main allergen in about three quarters of cases (74.7%), with PG responsible for a further 17.1% ^[4]. An earlier case series had pointed at PG as the usual culprit and suggested alternative solvents for affected patients ^[3].

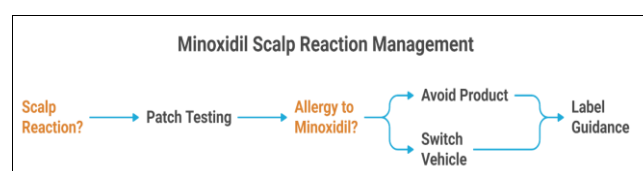


Fig 1: Clinical Decision Pathway for Managing Topical Minoxidil Scalp Reactions

Irritation is a separate and more common story. A 2025 review in *Acta Dermato-Venereologica* asks directly whether scalp reactions to minoxidil are true allergy or simple irritation, and the answer matters because it changes what a patient should do next; patch testing helps sort the two out ^[11].

For formulators, two things follow. First, a vehicle free of PG and low in ethanol removes the best-documented vehicle triggers. Second, it does nothing for people who are allergic to minoxidil itself. Any honest product file therefore needs clear label advice and, where appropriate, patch-test guidance, rather than a blanket claim of gentleness.

Figure 1 demonstrates a schematic decision tree illustrates the clinical management workflow for minoxidil induced scalp reactions, outlining how patch testing differentiates active drug allergy from vehicle sensitivity to guide proper product selection or formulation adjustment.

Reaching the follicle: what the delivery science says

1. The pilosebaceous unit as a route

The hair follicle, its shaft and the attached sebaceous gland make up the pilosebaceous unit. It has long been studied as a route for delivering drugs to the skin, and early work already showed that liposomes can direct drug to it ^[19]. This has been demonstrated in Figure 2. Follicles are attractive because they are surrounded by a rich capillary network, immune cells and stem cell niches. The upper follicle behaves like a reservoir: particles gather at the openings and move down the follicular canal.

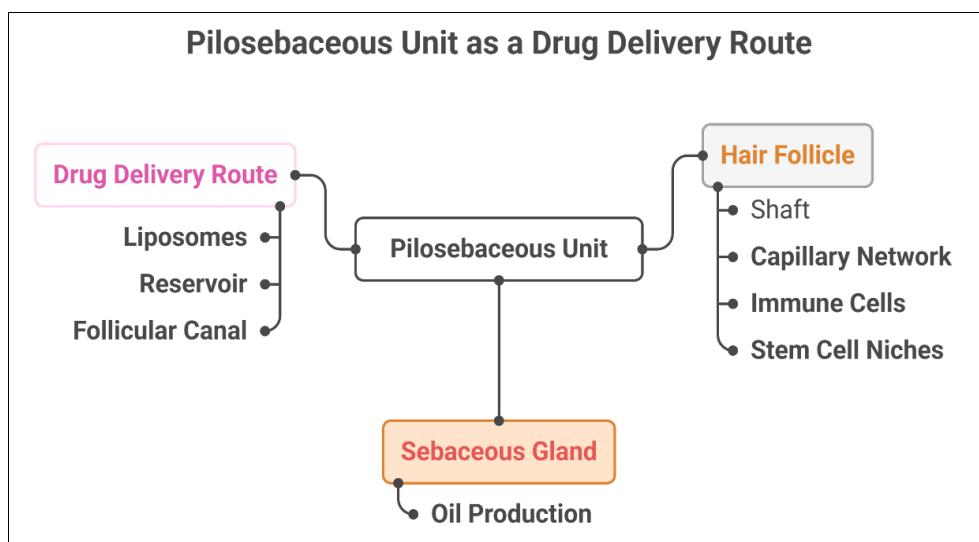


Fig 2: Schematic Overview of the Pilosebaceous Unit as a Targeted Drug Delivery Route

2. Particle size, massage and sebum

One of the best-known experiments used dye-loaded particles of about 320 nm. With massage, the particles went markedly deeper into pig follicles than the same dye applied without a particle carrier, and in human skin they stayed in the follicles for up to 10 days compared with about 4 days for the non-particle form. The authors suggested that the movement of the hairs works like a pump ^[12]. Reviews of follicular nanoparticle delivery describe particle carriers as a way to improve penetration depth and residence time, while excess sebum or a blocked follicle may limit uptake ^[13].

This is worth saying plainly to consumers and to brand partners: how the serum is applied is part of how it works. Clean scalp, application along the partings and a short massage are not cosmetic niceties, and the directions for any Lipoedge™ serum should be tested rather than assumed.

3. A caution about the evidence

The follicular-targeting literature is messier than the enthusiasm around it suggests. 2023 methods review points out that differences in skin model, the skin layer analyzed, controls and extraction methods make studies hard to compare, and sometimes hard to trust ^[8]. In the minoxidil liposome work itself, deposition in skin improved but no drug was found crossing the full skin thickness *in vitro* ^[5]. Any developer, WBCIL included, will need its own follicle-resolved data gathered with a harmonized method rather than leaning on other groups' results.

Liposomal and related carriers for minoxidil: the published record

Table 1 lists representative studies. All are preclinical, and none involve WBCIL.

Table 1: Representative preclinical studies of vesicular and nanocarrier minoxidil

System	What was reported	Limits	Reference
Liposomes and niosomes vs solution; <i>ex vivo</i> skin	Liposomes delivered more minoxidil to the epidermis and dermis than niosomes or solution. Alcohol-free liposomal formulations were proposed for hair loss. No drug crossed the full skin thickness.	<i>Ex vivo</i> ; no efficacy endpoint	Mura <i>et al.</i> , 2007 ^[5]
Neutral, positive and negative liposomes vs a non-liposomal formulation	Neutral liposomes gave the highest pilosebaceous deposition, then positively charged, then negatively charged; the non-liposomal formulation gave the lowest. Stability work pointed to refrigerated storage.	<i>Ex vivo</i> ; informs charge and storage	Jain <i>et al.</i> , 2010 ^[6]
Lipid nanoparticles carrying minoxidil (with finasteride); <i>in vitro</i> release and penetration	Particles in the range suited to dermal and follicular reach, with sustained drug release.	Different carrier class; <i>in vitro</i>	Gomes <i>et al.</i> , 2014 ^[20]
Fatty-acid vesicles in a gel; <i>ex vivo</i> skin	Designed to take advantage of sebum fatty acids for follicular targeting.	Different vesicle class; <i>ex vivo</i>	Oleic acid nanovesicles, 2018 ^[21]
Hyaluronic acid–lecithin liposomes with minoxidil and a nitric oxide donor; mouse AGA model	About 200 nm vesicles raised skin minoxidil versus a commercial 2% tincture. Nitric oxide co-delivery added capillary dilation and better regrowth. The tincture dried and flaked the mouse skin; the liposomes were well tolerated.	Animal; a correction was later published; NO donor is experimental	Xing <i>et al.</i> , 2023 ^[7]
Minoxidil in flexible liposomes fused with dermal papilla cell exosomes; mouse AGA model	Faster hair regeneration than free minoxidil without notable skin irritation.	Animal; complex early-stage platform	Exosome–flexible liposome hydrogel, 2024 ^[22]

1. What can be said, and what cannot

- **Reasonably supported:** carrier-based, low-solvent minoxidil can increase skin or pilosebaceous deposition compared with plain solution in laboratory models.
- Reasonably supported (animals): the skin damage seen with a solvent tincture can be avoided with a liposomal vehicle ^[7].
- Not established: that any liposomal minoxidil serum grows more hair than a marketed 5% solution or foam

in people. We found no controlled human trial of such a serum.

- Still open: the best surface charge. Neutral liposomes performed best for pilosebaceous deposition in one study ^[6], while a clearly negative charge usually helps colloidal stability. This has to be settled by experiment for each formulation.

Where Lipoedge™ by WBCIL fits

1. Why a liposomal platform is a natural base?

WBCIL (West Bengal Chemical Industries Limited) is a Kolkata-based manufacturer that has built a liposomal technology programme alongside its pharmaceutical and fine-chemical business. Lipoedge™ is the name WBCIL uses for that liposomal platform. Because the platform already handles phospholipid vesicles for other actives, the

know-how around making, sizing, analysing and stabilising liposomes does not have to be built from nothing for a minoxidil serum.

That said, nothing about minoxidil is a drop-in. The drug has limited water solubility, which makes high loading at 5% a genuine technical challenge, and each active added to the system can shift pH, charge and stability. These are questions for the development programme, not claims we can make today.

2. Design questions the Lipoedge™ minoxidil serum must answer

Table 2 sets out the main design decisions in plain terms. We give no target numbers for Lipoedge™ because none have been measured for this product.

Table 2: Key development questions for a liposomal minoxidil serum

Question	Why it matters	How the literature guides it
Strength (2% or 5%)	Regrowth was greater at 5% in men, but irritation was too ^[16] . Loading minoxidil into vesicles at higher strength is difficult.	Evaluate both; report how much drug is inside the vesicles versus free in the water phase.
Vesicle size	Particle-based carriers of a few hundred nanometres have shown good follicular uptake.	Define a size window and test uptake in follicle-resolved models.
Surface charge	Charge affects both deposition and stability.	Screen a range from neutral to mildly negative and choose on data.
Free versus encapsulated drug	Free minoxidil behaves like an ordinary solution, so it dilutes any benefit of the carrier.	Measure encapsulation and the free fraction during stability studies.
Solvent system	PG and high ethanol are the best-documented vehicle irritants.	Use an aqueous, PG-free and low-ethanol base.
Storage and stability	Liposomes can be sensitive to temperature; one study pointed to refrigerated storage ^[6] .	Run full stability, light and in-use studies before choosing packaging.
Application format	Massage and application technique influence follicular uptake ^[12] .	Test the serum in the way consumers will really use it.

Looking after the scalp environment around the follicle

1. The biological case

AGA is not simply a matter of a drug failing to arrive. In one study, people with AGA had lower superoxide dismutase activity and signs of greater oxidative stress in their blood than controls ^[9]. In laboratory work, dermal papilla cells from balding scalp showed weaker mitochondrial function, lower ATP and more oxidative stress than cells from non-balding scalp, and applying an antioxidant improved some of these measures ^[10]. These

findings support, but do not prove, the idea that antioxidants and barrier-supportive ingredients belong in a minoxidil serum.

2. Candidate ingredients and how far the evidence goes

Table 3 is deliberately cautious. For most of these ingredients we found no clinical trial of a topical liposomal combination with minoxidil, so the right wording on a label or a brochure is "supports the scalp environment", not "boosts regrowth".

Table 3: Possible companion ingredients

Ingredient	Reason to consider it	Evidence status and caution
Glutathione, vitamin C, coenzyme Q10, alpha-lipoic acid	Antioxidants that address the oxidative stress and mitochondrial changes seen in AGA.	Rationale is mechanistic. No topical hair-regrowth trial is cited here. Compatibility with minoxidil, pH, colour and odour must be tested.
Hyaluronic acid	A humectant; incorporated into the liposome membrane in one minoxidil study ^[7] .	Animal data in a combination model only. Choice of molecular weight affects viscosity.
Niacinamide	Widely used to support the skin barrier in leave-on products.	We cite no scalp-hair study; position as comfort and barrier support only.
Caffeine	In an open-label trial in men, a 0.2% caffeine liquid was non-inferior to 5% minoxidil solution ^[24] .	Open-label and in one population. Not a liposomal product. Check regulatory status when combined with minoxidil.

Safety and regulatory points

- **Local tolerability:** A PG-free, low-ethanol vehicle addresses a recognised source of irritation, but anyone allergic to minoxidil itself should avoid every minoxidil product. Labels should tell users to stop if they develop a rash, severe itching or swelling.

- **Systemic exposure:** Normal scalp absorption is low but rises with strength, frequency and damaged skin ^[1]. *In vitro* work found minoxidil retained in skin layers rather than crossing the full thickness ^[5], which is reassuring but no substitute for *in vivo* exposure testing against the reference product.

- **Children and accidental exposure:** Marketed minoxidil labelling warns about contact between treated skin and young children and about accidental swallowing of liquids. A serum should carry the same cautions and sensible packaging.
- **Regulatory status:** Minoxidil is a drug active, and a serum containing it is generally regulated as a medicine, not a cosmetic. Permitted strengths, claims and the data needed to support a new vehicle differ between countries, so regulatory advice should come before commercial planning.

What a credible evidence package would include

A defensible dossier for a Lipoedge™ minoxidil serum would cover four things. The first is physical and chemical quality of the vesicles and the drug: size distribution, charge, how much drug is encapsulated, and how all of these hold up over shelf life. The second is performance: drug release and, importantly, skin and follicular deposition compared with a reference solution at equal dose, measured with an agreed method [8]. The third is safety: irritation and sensitization testing and an assessment of systemic exposure. The fourth, eventually, is clinical: a controlled study against a marketed reference, perhaps with a biomarker such as follicular sulfotransferase activity to see who benefits most [2].

What this means for partners and for consumers

1. For B2B partners

Pharmaceutical and cosmeceutical brands, trichology clinics and distributors usually ask the same few questions. Can the supplier make the product reliably at scale? What technical and regulatory documents come with it? What can the brand actually claim? And will patients tolerate it? A liposomal platform with in-house manufacturing experience, which is what WBCIL offers under Lipoedge™, is relevant to the first two. The last two depend on data that still has to be generated, and partners should ask to see it as it arrives.

- **Brand owners and OTC companies:** ask for a comparability plan against the reference product, stability data and a regulatory pathway note for each target market.
- **Derma-cosmeceutical and trichology brands:** ask for a compatibility matrix for add-on actives and tolerability data before building claims around them.
- **Clinics and practitioners:** a PG-free option may suit patients who have struggled with the usual solutions, with clear counselling on patch testing [11].
- **Export distributors:** ask for market-specific classification and labelling support early, since rules differ.

2. For consumers (B2C)

The questions people ask about minoxidil are fairly consistent: why does it itch and flake, will it work for me, is a stronger one better, and is a liposomal or alcohol-free one actually any different? The table below suggests answers that match the evidence. It is a guide, not approved claim language, and local regulations will shape what can be printed.

Table 4: Consumer questions and evidence-aligned answers

What people ask	An honest answer
"Minoxidil makes my scalp itchy and flaky."	This serum is designed without propylene glycol and with little or no ethanol, two ingredients linked to scalp reactions.
"Will it work for me?"	Results differ from person to person, partly because of how the follicle processes the drug [2].
"Is liposomal delivery better?"	In laboratory studies liposomes have increased the amount of minoxidil reaching skin and follicles [5, 6, 7]. Results for this product will be shared once measured.
"What else helps the scalp?"	Antioxidant and moisturizing ingredients are included to support the scalp environment.
"How should I use it?"	Apply to a clean, dry scalp, massage gently, follow the label and wash your hands afterwards [12].

3. One-sentence positioning

The most defensible line for a Lipoedge™ minoxidil serum is something like: "a scalp-comfort-focused minoxidil serum from WBCIL, built on liposomal technology and supported by ingredients that look after the scalp." It borrows trust from minoxidil's long clinical record, differentiates on the vehicle and delivery approach, and leaves performance claims to the product's own evidence.

Limitations

Evidence for liposomal minoxidil is preclinical and varies a lot between studies [8]. We found no controlled human trial of a liposomal minoxidil serum. This review contains no measurements from the Lipoedge™ minoxidil serum, which is yet to be launched. The case for several companion ingredients is mechanistic or indirect, and the caffeine trial was open-label [23]. This is a narrative review, not a systematic one. Search coverage was targeted, and relevant studies may have been missed.

Conclusion

Topical minoxidil works for many people, but the experience is held back by vehicle irritation, modest

delivery and uneven response. Liposomal carriers are a sensible response: independent preclinical studies show better deposition and gentler behavior on skin [23], and what we know of AGA biology supports adding scalp-supportive ingredients [9,10]. Lipoedge™ by WBCIL gives a credible technical base for building such a product. Whether it earns its place with partners and consumers will depend on the deposition, safety and clinical data that the programme now needs to produce.

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Author Contributions

All authors contributed equally to conceptualisation, literature review, analysis, writing, and editing. Mr Sunil Agarwal provided supervision and guidance.

Conflict of Interest

The authors declare that the review discusses the Lipoedge™ platform developed by WBCIL. All scientific

evaluations, literature comparisons, and conclusions presented in this manuscript are objective, evidence-based, and free from commercial bias.

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