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Research Article

OPTIMIZING HAIR TRANSPLANT OUTCOMES: INTEGRATION OF AI, ROBOTICS, AND STEM CELL THERAPIES

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ABSTRACT

The rising incidence of hair loss coupled with its significant emotional impact has been the main factor in the increased demand for the development of more effective hair restoration methods. One of the most common problems that traditional hair transplant methods have is the difficulty of achieving the right density and a natural look, especially in patients with a limited donor area or with complex hair loss patterns. This article reviews the recent innovations in hair transplantation, focusing primarily on the increase of hair thickness and density for more natural results. The most important innovations are AI-assisted graft selection, robotic hair transplantation systems, stem cell therapy, and advanced drug delivery techniques. AI and robotics have been very helpful in achieving more accurate, faster, and more personalized results, and as an example, the ARTAS Robotic System can achieve less than one millimeter accuracy in follicular units harvesting. One of the ways to improve the graft survival rate is the use of stem cell therapies, especially those involving adipose-derived stem cells and the stromal vascular fraction; through neovascularization and diminished fibrosis, they can elevate the rate to 87%. The first-come-future treatments, like exosome therapies and 3D bioprinting, open up new possibilities for hair regeneration with a very low risk of immunogenicity. The use of these innovations has made the integration of the procedures quicker and less traumatic for the patients, which is why their satisfaction is reportedly higher now. These innovations, which overcome the shortcomings of the old methods and put a spotlight on density optimization, signify a great leap forward in hair restoration and offer better options for people who are looking for hair with improved thickness and density than what was possible before.

Keywords: Hair transplantation, Density enhancement, Innovative techniques, AI technologies, Hair follicle mapping.

INTRODUCTION

The need for hair restoration has been mainly caused by the increased frequency of hair loss and the extensive impact this has had on the mental and physical health of the affected people. Hair loss, especially androgenetic alopecia (AGA), is a problem that affects a very large number of people of all ages and genders (Almashali *et al.*, 2023; Pozo-Pérez *et al.*, 2024). AGA is a condition that affects more than 80% of men and about 50% of women by the age of 70 years, with the risk of getting it increasing with the age (Mansouri *et al.*, 2005). Half of the male population will have hair loss by the time they are 50 years old, and one in four will have hair loss by their 49th year, increasing to more than half by the age of 79. A study conducted in India revealed a 58% prevalence of hair loss in men aged 30-50 years (Dhurat *et al.*, 2025). Data from an Israeli Dermatology Clinic, indicate the rate of hair loss-related cases has increased considerably during the last decade, shot up from 1.24% in 2010 to 9.44% in 2020, with AGA prevalence changing from 17% to 32% correspondingly (Devjani *et al.*, 2023). The rate for alopecia areata in the U.S. was estimated to be consistently increasing and ranged between 91.46 and 92.90 overd 100,000 person-years from 2016 to 2019. Most notable of all is the prevalence of hair loss among children, which has been doubled in the last ten years, thus, the trend of hair loss has become much earlier in onset (Liu *et al.*, 2024).

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The worldwide market for AGA treatment is estimated to generate about 4 billion USD annually (Devjani *et al*., 2023). The hair transplant industry has experienced a massive growth, the total market for hair restoration surgical procedures has had a 10% rise, increasing from 4.1 billion USD in 2016 to 4.6 billion USD in 2019 (Kim *et al*., 2022). Hair loss is strongly associated with the decrease of life quality, self-esteem, and mental health, leading to confidence drop and social anxiety (Al Najjar *et al*., 2023; Devjani *et al*., 2023). Due to this, the demand for the treatment of hair loss, as well as the associated health burdens, has been rising continuously (Liu *et al*., 2024).

Even though the traditional treatment methods (topical minoxidil and oral finasteride) are FDA-approved, they are often accompanied by limitations such as effects only being temporary, incomplete regrowth, slowly starting to have an effect, possibility of side effects, and symptoms will return once the treatment is stopped (Dhurat *et al*., 2025; Liu *et al*., 2024). Hair transplant, although the solution, is constrained by the insufficiency of hair follicle donor sites, which leads to dissatisfaction among patients (Dhurat *et al*., 2025). This situation calls for uncovering new and better therapeutic choices. The perception of "lack of special solution with present medical technology" for AGA is one of the reasons that leads to a demand for innovative approaches (Wu *et al*., 2021).

Hair restoration demand increase is a consequence of the widespread nature of hair loss and the shortcomings of traditional treatments that have led the field to seek more precise, targeted, and regenerative solutions. This paper is mainly concerned with the latest developments in the area that are intended to increase hair thickness and density in transplantation procedures, thus filling a critical gap in the literature that mostly focuses on general improvement rather than specific-density optimization.

EVOLUTION OF HAIR TRANSPLANTATION TECHNIQUES

The first hair transplant operation can be traced back to the work of the Japanese doctor Shoji Okuda in 1937 (Thuangtong *et al*., 2025; Wu *et al*., 2021). Over time, the procedure has undergone significant changes and improvements resulting in today’s advanced techniques which make the operation safer and more effective (Thuangtong *et al*., 2025). The strip method or Follicular Unit Transplantation (FUT) is a technique that entails the removal of a donor area of the scalp (usually the back of the head due to its resistance to androgen) and subsequent separation of individual follicles to be implanted into hairless areas (Liu *et al*., 2024). Some of the benefits are that the hair follicles are more visible at the time of extraction, thus cutting down on the number of transection and bleeding. It is possible to get more hair follicles from longer ellipses of less than 1 cm in width. The most notable drawback is the linear scar that results from the incision (Garg & Garg, 2018; Gasteratos *et al*., 2024). The new hair can be seen only after at least 3 months which is the shortest time needed for the transplanted hair to reach the anagen phase (Liu *et al*., 2024).

Hair transplant surgery requires a lot of physical work and takes a long time and so it is usually a source of fatigue for the surgeon (Thuangtong *et al*., 2025). The solution has therefore been the use of robotic systems in this area. Robotics-assisted systems like the ARTAS Robotic System use computer vision to locate healthy follicular units that can be harvested with very high accuracy thus helping to reduce scars and increase graft survival rates (Thuangtong *et al*., 2025). These devices have the potential to do 500-800 grafts per hour and also to remove the operator’s fatigue (Gasteratos *et al*., 2024). In back to the future mode, it is a fact that early robotic systems were designed either for harvesting or implantation, however, the current development of integrated image-guided robotic systems is aimed at allowing them to perform both functions without interruption (Thuangtong *et al*., 2025). Moreover, the use of AI in aesthetic medicine is also intended to simplify diagnostics, enhance results, and offer a more personalized patient care. One of the AI-driven technologies could be hair density measurement which would become more precise and less time-consuming when done by a machine rather than by a human (Kim *et al*., 2022). Overall, hair transplantation has been transformed from laborious manual invasive techniques to sophisticated, precision-driven, and in most cases robotic-assisted methods where unlike before, great emphasis is placed on graft quality, the patient's minimum discomfort and the surgeon's better working conditions (Thuangtong *et al*., 2025).

CURRENT GOLD STANDARDS IN HAIR TRANSPLANTATION

Hair transplantation through Follicular Unit Transplantation (FUT) remains the most effective and widely accepted method. The procedure that follows in general is cutting away the hair source; in the most common case, hair roots are separated from the back of the head as this part of the scalp is known as the one that is most resistant to androgen induced hair loss and then the cutting away hair is implanted on the bald area (Liu *et al*., 2024).In the strip method a piece of the scalp is taken from the back of the head. The taken hair follicles are then separated and grafted to the place where a hole is made to the recipient site. Another technique for graft removal is follicular unit extraction (FUE) (Liu *et al*., 2024).

Declaredly, hair transplant surgery results in a natural hairline both in males and females. Usually, the operation is a permanent one as the graft survival rate is higher than 90% in AGA patients. Observing the result of transplantation requires at least a three-month period (Gasteratos *et al*., 2024). The combination of hair transplantation with other procedures in the form of medicines such as oral finasteride, topical minoxidil, and platelet-rich plasma (PRP) is possible and with these, the hair transplantation effect will be better. Nevertheless, the shortage of donor hairs remains a major problem that will continue to limit the level of satisfaction among patients of hair loss (Liu *et al*., 2024). Hair transplantation is essentially about the redistribution of the existing hair, not the creation of new ones.

The surgical considerations include the following

Donor Area

The cutting off should be limited to a "safe donor area" (SDA) only, usually 189-203 cm^2, the exact size depending on individual and ethnic differences. The removal of hair from non-safe areas is not recommended because hairs taken from these areas may eventually be lost (Park, 2023).

Magnification

The use of good magnification devices, such as stereo microscopes, video microscopes, and magnifying loupes, is highly suggested for FUE procedures to locate the follicular unit angle of the exit and get a better cut without a transection. The most perfect dissection is done under a stereomicroscope at 10-25x magnification with good view (Park & You, 2017).

Graft Handling

The out-of-body time for grafts has been witnessed up to 6 hours, however, it is still better to place the grafts within the first 2-4 hours to be on the safe side with the survival rate (Park & You, 2017).

Duration

There is no clearly defined limit for the longest duration of the surgical operation; nevertheless, conditions such as the safety and comfort of the patient, the tiredness of the doctor and assistant, the time of anesthesia, and the patient's general state of health should be taken into account. It is better that the operation be performed in several sessions when the number of grafts is large than prolonging a single session (Parsley & Perez-Meza, 2010).

Hairline Design

The front hairline design is the most critical and also the most difficult one. The design must be natural not only for the present but also for the future face changes, should not be detectable, and should have a reasonable density. The decision on where to place the hairline can be made after taking into account the person's age, hair characteristics, facial features, sex, and ethnicity. It should be rather higher on the forehead since a lower hairline can always be changed afterwards, but the other way around is not possible (Sirinturk *et al*., 2016). The risks and side effects of this procedure include, among others, accidental reactions to anesthesia, pain, edema, bleeding, and patient dissatisfaction. Prior to FUE, patients with scarred scalp tissues can benefit from autologous stem cell therapy that has shown not only hair density improvement but also graft survival rates (Al-Dhubaibi *et al*., 2025). This procedure induces neovascularization (70% of new blood vessels) and reduces fibrotic tissue (50% less) in scars, hence providing a suitable microenvironment for the transplanted follicles.

BREAKTHROUGH TECHNOLOGIES ENHANCING RESULTS

Advanced Stem Cell and Regenerative Therapies

Stem cell-based therapies are gaining more popularity as they are considered the most promising solutions because of their regenerative and immunomodulatory features. The studies also reveal that both cellular and acellular stem cell therapies are safe and efficacious in stimulating hair growth and increasing hair density (Wu *et al*., 2021). The different cell sources are: human hair follicles, adipose tissue, umbilical cord blood, bone marrow, and exfoliated deciduous teeth (Zhang *et al*., 2021). The acellular interventions use conditioned media or extract from stem cells rich in growth factors (VEGF, PDGF, and EGF), cytokines, and chemokines (Ferruggia *et al*., 2024). These elements perform paracrine functions; thus growth is directly promoted in the follicle by the activation of stem cells and the induction of telogen-to-anagen conversion (M. Kim *et al*., 2022).

Adipose-Derived Stem Cell (ADSC) Extracts/Conditioned Media experiments have demonstrated that the local use of a solution can lead to a remarkable increase in hair amount. In the same way, human ADSC-conditioned medium has resulted in higher hair densities, particularly when combined with a non-ablative fractional laser or topical minoxidil (Wu *et al*., 2021). ADSC-exosomes, very small vesicles released from cells, are a biologically active substance and a potent cytokine mixture that promotes hair growth with a low risk of the development of immunity in the organism. In vivo studies have shown that these exosomes can bring about the proliferation and the migration of dermal papilla cells, up-regulate VEGF and IGF-1 secretion, and shorten the telogen phase in mice (Gasteratos *et al*., 2024; Wu *et al*., 2021).

The Stromal Vascular Fraction (SVF) from which fat has been removed, is the radical solution that is regarded as the next generation of hair regeneration methods. The use of autologous SVF for transplantation has led to a very noticeable increase in hair density and scalp keratin improvement in a period of six months, with a high level of patient satisfaction having been reported (Popescu *et al*., 2024). New peptides represent the next major breakthrough. AIMP1-derived peptide (TN41), a factor secreted by hair follicle stem cells, stimulates dermal papilla cells without triggering any inflammatory response, thereby leading to an increase in the production of genes that foster growth and a decrease in that of growth inhibitory genes (S. J. Kim *et al*., 2021). This peptide supports the elongation of hair in cultured human hair follicles and ameliorates hair-inducing capacity.

The move to use stem cells as a pre-treatment method for hair transplant has netted excellent results in the past. The use of one's own stem cells as a therapy before performing FUE on scarred tissues has led to visible changes, as mean hair density has been raised by 45%, and the graft survival rate is 87% as compared to FUE only (Al-Dhubaibi *et al*., 2025). Attribution in this case can be made to the neovascularization effect (70% more new blood vessels) and the decrease in fibrosis (50% less fibrotic tissue).

Innovations in Hair Transplant Techniques and Devices

Among several changes, one important transformation in hair transplantation has been made in the area of FUE, with the changes being more or less directly related to the aspects of precision, efficiency, and patient comfort (Nestor *et al*., 2021; Park *et al*., 2021). Some of the ergonomic improvements are the lightness of the handpieces (95 g in the lightest model) and a foot pedal that reacts 360 degrees to the operator's movements and helps to relieve fatigue. Advanced punching mechanisms come with features like Bluetooth operation, fingertip touch sensors, and multiphasic movement. Very high-resolution microscopes connected to full HD monitors take graft inspection and dissection to a new level (Park *et al*., 2021). By means of softness of the grip on the Rainbow™ implanter and recognition of the direction of the bevel by the touch of the hand, the damage to the soft tissue is significantly reduced. Hair Follicular Unit Extraction using Long Hair method not only can fetch the hair follicles with the hair shaft still attached but also enables visualization of the donor area and makes the operation easier (Park *et al*., 2021).

Artificial Intelligence and Robotics in Hair Restoration

Artificial Intelligence is restructuring in a big way the field of aesthetic medicine by making it more precise, personalized, and automated. Among the robotic hair transplantation systems, the ARTAS Robotic System is the most advanced one which employs computer vision to locate the most viable follicular units and then cuts them out with an accuracy of less than a millimeter (Zhu *et al*., 2024). An image-guided robotic system with the integration of multiple components like the image-guidance, a dual-function needle mechanism, and the robotic platform provide an efficient way to perform the process (Thuangtong *et al*., 2025). Automatic Hair Density Measurement is attributed to deep learning technologies like YOLOv4 which make the whole process of hair density measurement fully automatic and thus provide easy assessment of hair loss and donor area condition (M. Kim *et al*., 2022). Personalized Treatment Planning utilizes machine learning algorithms to sift through diverse patient data and come up with the best treatment recommendations, thus saving time and effort of trial-and-error. Predictive Outcome Modeling employs AI to predict patient responses and the probability of complications, thereby ensuring safety and creating trust (Pavunraj *et al*., 2025).

Advanced Drug Delivery Systems and Formulations

Drug treatment is not limited to oral and topical medications; novel delivery methods are investigated. Nanoparticle Delivery employs lipid-based nanoparticles to stabilize drugs, increase solubility, and provide long-term release. Microneedles help drugs to penetrate the scalp, thus absorption is improved, and treatment effectiveness is increased. With 3D Printing, customized drug-loaded scaffolds are created for gradual release and, therefore, maximum therapeutic effects (Herrera-Rivero *et al*., 2020). Innovative Topical Formulations like Cuticapil Stem Hair Serum containing natural active ingredients have shown a considerable decrease in hair shedding and density improvement (Dhurat *et al*., 2025).

SPECIAL TECHNIQUES FOR CHALLENGING CASES

Treating Hair Loss on Scarred Tissue

In a traumatic situation or fire, the occurrence of scars on the scalp accompanied by hair loss can be misleading to perform just a conventional FUE method. A new method before FUE involves autologous stem cell therapy, which significantly increases hair density, graft survival, and rejuvenates the scarred tissue (Al-Dhubaibi *et al*., 2025).

Tissue Engineering and 3D Bioprinting for De Novo Hair Follicle Regeneration

In the case of cicatricial alopecia where the hair follicle is replaced by scar tissue, tissue engineering has the potential to provide solutions by creating epithelial-mesenchymal interactions (Thuangtong *et al*., 2025). The team uses different types of cells such as hair follicle stem cells, dermal papilla cells and 3D cell culture systems to form spheroids that recreate the natural microenvironment in vivo (Thuangtong *et al*., 2025). 3D Bioprinting uses biomaterials like placenta-derived extracellular matrix to fabricate scaffolds that are able to regenerate tissue appendages like hair follicles (J. Kim *et al*., 2025).

Overcoming Donor Site Limitations

For extreme hair loss (e.g., Norwood/Hamilton stages V-VII) one can resort to combination techniques. This may include the combination of FUT and FUE methods or the collection of hair from several body areas (Gasteratos *et al*., 2024). Stem cell therapy is a potential solution for the problem of hair growth stimulation, especially in cases of AGA that is resistant to other therapies. These consist of cellular therapies, e.g. the use of autologous mesenchymal stem cells derived from hair follicles, and acellular therapies, where no cells but only conditioned media are used (Wu *et al*., 2021).

EMERGING AND EXPERIMENTING APPROACHES

Hair Cloning and Follicular Regeneration

Among these different avenues, one can found stem cell therapeutics being the most innovative and ground-breaking in the realm of hair cloning. Various research have pinpointed the potential of Dermal Papilla Cells (DPCs) together with Hair Follicle Stem Cells (HFSCs) as these two cell types are natural precursors of hair follicle growth and regeneration. It has been reported that DPC implantation in situ highly contributes to the induction of new hair follicle formation (Li *et al*., 2023). Both Stromal Vascular Fraction (SVF) and Adipose-Derived Stem Cells (ADSCs) were able to demonstrate a significant improvement in hair density (Wu *et al*., 2021). The use of Inducing Pluripotent Stem Cells (iPSCs) is greatly helped to the regeneration of different cell types in hair follicles (Liu *et al*., 2024).

Tissue Engineering and 3D Bioprinting

One of the important benefits of tissue engineering is the stimulation of interactions between epithelial-mesenchymal and cell-extracellular matrix, thus it significantly contributes to hair follicle regeneration. Cell-only transplantation (2D and 3D cultures) means the injection of a mixture containing epidermal stem cells and DPCs or the co-transplantation of aged HFSCs with young DPCs to generate new hair follicles (HFs). 3D cell cultures, like spheroids, help to create a similar in vivo microenvironment (Thuangtong *et al*., 2025). Hair follicle regeneration supported by biomaterial basically utilizes material that resembles not only the mechanical properties but also the chemical composition of hair follicle ECM to regulate cell behavior and differentiation. 3D printed skin equivalents using HAMA/GelMA are capable of simulating hair follicle structures (Kang *et al*., 2022; Thuangtong *et al*., 2025).

Novel Molecular Targets and Peptides

Wnt activators play an essential role in the formation of hair follicle and its regeneration. Small-molecule Wnt modulators and GFRA1 agonists synthetized by the cells significantly enhance hair follicle proliferation (Herrera-Rivero *et al*., 2020).AIMP1-Derived Peptide (TN41) is an activator of DPCs which in turn causes hair shaft elongation and enhancement of hair-inducing activity. The peptide accomplishes this by stimulating essential pathways in DPCs and facilitating the transcription of hair cycle-stimulating factors (S. J. Kim *et al*., 2021). On the other hand, there are factors like bFGF, VEGF, IGF-1, PDGF, and KGF which can induce hair growth through the mechanism of prolonging the anagen phase and activating cell proliferation (Herrera-Rivero *et al*., 2020).

PATIENT EXPERIENCE AND RECOVERY

Minimally Invasive Options

Minimally invasive hair restoration methods improve the patient experience as they allow for quicker recovery, lesser downtime, and are generally more comfortable for the patient (Nestor *et al*., 2021). In comparison with follicular unit strip surgery, FUE is associated with less pain after the operation and the scalp is not left with strip scars (Liu *et al*., 2024). Robotic technologies like the ARTAS Robotic System contribute to accuracy and the surgeon's mental well-being as they are less tiring and thus the patient benefits more (Thuangtong *et al*., 2025). The comfort of patients during operations has been elevated with the help of the ingenious ergonomic concepts of the surgical gear such as motorized forehead-supporting chair systems and fingertip recognition sensors (Nestor *et al*., 2021).

Stem Cell-Based Therapies

Stem cell-based therapies are assumed to be quite a good solution when it comes to the restoration of hair and the increase of its density (Wu *et al*., 2021). In the case of scar tissue, the use of the patient's own stem cells resulted in a significant improvement with the average increase of hair density 45% higher and the graft survival rate 87% (Al-Dhubaibi *et al*., 2025). The usage of Stromal Vascular Fraction (SVF), which is usually obtained from fat tissue through the procedure of liposuction, has led to very significant increases in hair density as well as keratin scores within 6 months (M. Kim *et al*., 2022).

Platelet Rich Plasma (PRP)

PRP is an autologous blood preparation where blood is drawn from the patient, platelets are concentrated in the blood via centrifugation, and the resulting platelet-rich plasma is injected into the patient's scalp (Liu *et al*., 2024). A great advantage for patient convenience is that PRP is done in a doctor's office, with no other obligations, and the patient can go home right after the treatment (Gasteratos *et al*., 2024). After the injection, the patient may experience pain in the scalp, a burning sensation, and headache; however, these symptoms typically disappear within 10-15 minutes after the injection (Gasteratos *et al*., 2024). Various researches report that hair count and hair thickness measure should increase significantly (Gasteratos *et al*., 2024; Liu *et al*., 2024).

Exosomes

Exosomes derived from mesenchymal stem cells represent a very low risk of immunogenicity due to their acellular characteristics. The exosomes incorporate cytokines and growth factors that induce hair regeneration (Gasteratos *et al*., 2024). By inducing the proliferation and migration of human dermal papilla cells, the exosomes also help hair growth and make the cells of the follicle more resistant to reactive oxygen species, according to studies (Wu *et al*., 2021). Researchers have recorded an increase in average hair density and thickness after 12 weeks of treatment (Gasteratos *et al*., 2024).

FUTURE DIRECTIONS IN HAIR RESTORATION

Advanced Regenerative Medicine and Stem Cell Therapies

Further studies should mainly concentrate on ensuring the most efficient ways of the harvesting, preparation, and administration of the stem cells (Wu *et al*., 2021). IPSCs have the ability to open up more sources of cells for the purpose of hair regeneration; however, with the current differentiation process and tumor formation risk, there is still a problem (Liu *et al*., 2024; Thuangtong *et al*., 2025). Due to the immune-privileged nature of hair follicles, allogeneic sources of cells may be a possibility in the future (Xu *et al*., 2022). Exosomes and growth factors are never at rest in their optimization process for usual consumption.

Advanced Technologies in Hair Transplantation

Later machine systems used for the implementation of the hair transplant procedures will not only be more precise but also more efficient and adaptable in achieving the desired results (Thuangtong *et al*., 2025). 3D bioprinting will become more advanced, and so will the ability to create structures that are almost the same as the natural ones both in terms of their properties and the degree as well as the exactness of their reproducibility (J. Kim *et al*., 2025).

Novel Drug Development and Delivery Systems

Among different types of treatments for alopecia, the one with antibodies should be the first choice because of its accuracy in the direct targeting. The main molecular targets considered in the future are Wnt activators, TRβ-selective agonists, and lactate dehydrogenase modulators. The most advanced methods for drug delivery are represented by topical preparations that help to avoid side effects typical of systemic administration, nanoparticle-based delivery systems, and controlled release mechanisms (Kim *et al*., 2022).

Genomic and Biomarker-Based Research

With the help of AI, precision medicine will be realized through biomarker-based AI models and genomics, which in turn will make the treatment planning personalized (Kumaresan *et al*., 2021). Gaining insight into genetic control of human head hair follicles will give the scientists a hand in decoding the genetics of hair-related traits and disorders (Kim *et al*., 2024).

CONCLUSION

The desire for thicker and denser hair has led to many breakthroughs in recent years, with a variety of innovative treatments and technologies emerging from continuous research. These key advances include regenerative medicine, surgical techniques, drug development, and diagnostic tools that together create a bright future for patients with HCC. One of the major breakthroughs is the development of stem cell- and exosome-based therapies that have demonstrated efficacy in improving hair regeneration and density. In general, the diverse sources and applications of adipose tissue, hair follicles, bone marrow, and umbilical cord blood present several therapeutic options. Specifically, adipose-derived therapies, especially SVF and ADSC-Exos, have displayed dramatic changes not only in the hair density but also the satisfaction of patients with their safety profile, which is largely positive.

Precision and positive outcomes in hair transplantation have been elevated by novel surgical techniques and ergonomics. The enhancements in FUE and the introduction of the robotic system have made it easy to harvest grafts while the surgeons' workload is lowered. A significant breakthrough in the evolution of hair transplantation for patients with multifactorial hair loss is the integration of stem cell therapy with FUE on scar tissue. The promising new directions for hair follicle regeneration lie in tissue engineering and biomaterials via 3D bioprinting and biomaterial-assisted regeneration. Novel drug development and nutraceuticals, including emerging therapeutic targets and AI in hair density measurements, provide more targeted and effective solutions. The future of people who are willing to have thicker and denser hair is becoming brighter at a fast pace due to the progress made in different areas of treatments. Combining these technologies have resulted in less time-consuming and more efficient operations making the patients happier. Although there are still some problems, the field is gradually moving towards more personalized, effective, and patient-friendly ways of attaining the best hair density and thickness. Hair restoration in the coming years will be most successful if the regenerative medicine, advanced surgical techniques, and personalized therapeutic approaches continue being integrated. One can say that the result of this integration is the patients' natural-looking and sustainable solutions to their hair loss concerns.

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CONFLICT OF INTERESTS

The authors declare no conflict of interest

ETHICS APPROVAL

Not applicable

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AI TOOL DECLARATION

The authors declares that no AI and related tools are used to write the scientific content of this manuscript.

DATA AVAILABILITY

Data will be available on request

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