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Imaging-Guided Regenerative Aesthetics: A Review of PRP, Stem-Cell, and Fat-Derived Therapies in Interventional Radiology

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ABSTRACT

Background: The regenerative field of aesthetic medicine has placed a growing emphasis on using biologically derived, minimally invasive techniques through which tissue function and quality can be restored. Autologous (patient's own) therapies such as platelet-rich plasma (PRP), stem-cell-derived products, and fat-derived grafts have become common treatments for a variety of indications including facial rejuvenation, scar treatment, and hair restoration. Most of these treatments are currently performed with the aid of landmark-based methods for injecting, which can lead to inconsistent results and increased risks during procedures.

Rationale and Purpose: Interventional radiology offers the opportunity to use a more precise image-guided technique with the use of real-time imaging (i.e., ultrasound) to view vascular structures and soft-tissue planes as they are placed within the body. This allows for better needle placement and allows for the accurate delivery of biologic agents with significantly less risk of intravascular injections. The purpose of this narrative review is to describe the current body of literature regarding the use of imaging guidance to aid in the delivery of regenerative aesthetic medical procedures. It will address the following components: clinical efficacy, safety, regulatory aspects, and standardization of the imaging technique.

Methods and Results: A structured search of the literature was completed using PubMed, Embase, and the Cochrane Database from 2020 to July 2025.Based on the available studies, image-guided delivery of biologic medications does demonstrate an increase in procedural accuracy, improves the distribution of grafts within tissues, and leads to improved patient-reported outcomes when compared to traditional methods of injection. However, much variation exists in the methods of biologic preparation, methods to assess the outcomes, and length of time patients are followed the procedure.

Conclusion: Recent evidence has shown that imaging guidance can help increase both safety and reproducibility in various areas of the patient care continuum. However, there continues to be a lack of high-quality randomized trials demonstrating the benefits associated with imaging guidance and comprehensive standardized protocols for the utilisation of imaging guidance, which ultimately hampers the development of clinically significant evidence-based treatment algorithms. A need for additional multi-disciplinary studies is present to create valid and scientifically based guidelines for incorporating the use of interventional radiology within regenerative aesthetic practices.

Keywords: *Platelet-rich plasma; stem-cell therapy; fat grafting; regenerative aesthetics; interventional radiology; ultrasound-guided injection; imaging guidance.*

INTRODUCTION

Over the last decade, regenerative and interdisciplinary approaches to aesthetics have garnered significant interest from an expanding patient population seeking to return to a youthful, healthy state with less invasive techniques and with more permanent enhancement of their appearance. As opposed to traditional aesthetic medicine techniques that primarily employ synthetic fillers, neurotoxins, or surgical procedures, regenerative techniques in aesthetic medicine continue to promote and/or augment natural tissue quality and stimulate the body's own ability to regenerate damaged tissue and replace it with new, improving the appearance of the skin through enhanced collagen production, increased blood flow and healing, and improved structural support through improved skin texture, elasticity, and volume by the use of their own tissue through the use of autologous biomaterials such as PRP, stem cell-derived products, and adipose tissue-derived grafts.

Although regenerative aesthetic procedures are becoming increasingly prevalent, most are still being performed using the traditional landmark-based injection methods (surface anatomy & practitioner experience) which can vary significantly based on the individual (i.e. patient's vascular and soft tissue anatomy). As such, biologic materials that are placed inconsistently may result in inconsistent outcomes (i.e. not able to achieve desired effects), loss of durability of the outcome(s), and increased risk of developing complications (Risks include tissue ischemia; necrosis and/or, in rare cases, permanent blindness). In addition, it is critical that clinicians utilize image guided interventions to enhance procedural accuracy, thereby improving clinical outcomes.

Interventional Radiology now provides the framework for enhancing procedural accuracy by using real-time imaging guidance. The different modalities (i.e. Ultrasound, CT, Fluoroscopy) provide clinicians with direct vision of the vascular structures & the soft tissue plane and allow for accurate needle placement in relation to the injection of biologic material. Ultrasound is the most practical modality for use in aesthetic practice because the technology is readily available and does not involve exposure to ionizing radiation and provides the clinician with real-time, dynamic assessment capability. Providing clinicians with accurate tissue planes avoids injecting into critical vessels, thus ensuring uniform distribution of biologic materials throughout the defined treatment area.

In the present day, there is relatively little scientific evidence and there is considerable heterogeneity among studies pertaining to the use of imaging to provide guidance during regenerative medicine processes (i.e., platelet-rich plasma [PRP], stem cells, and fat transfer). The differences among these biologics with respect to preparation protocols, imaging modality types, outcome measures, and follow-up durations hinder the ability to make reasonable comparisons of efficacy between studies and create standards of practice. Therefore, to define the potential applications of interventional radiology for regenerative aesthetics, an assessment of all available scientific literature is warranted.

The present narrative review article serves to provide insights into how imaging is used to support the administration of PRP, stem cells, and fat to improve aesthetic outcomes. Consideration will be given to biological mechanisms, clinical efficacy, safety issues, and regulatory concerns as well as gaps in knowledge that require investigation to enhance both future research and practice in this area.

METHODOLOGY

The purpose of this narrative review is to synthesize and critically analyze the current literature regarding Imaging-Assisted Rejuvenation. This review was intended to consolidate current clinical practices, identify the evidence

supporting these practices, and highlight possible weaknesses within the field as opposed to being an exhaustive systematic review.

Literature Search Strategy

A systematic search of the bibliographic databases of PubMed, Embase, and the Cochrane Library was conducted on the complete range from database inception through July 2025. The databases used were chosen because of the extensive content they have included from all areas of biomedical/clinical/surgical research. Search terms used were a mixture of keyword and Medical Subject Heading (MeSH) terms including all of the following: regenerative aesthetics; platelet-rich plasma; PRP; stem cells; adipose-derived stem cells; fat grafting; stromal vascular fraction; ultrasound guided injections; CT-guided; interventional radiology. Boolean operators (AND and OR) were used as needed to narrow the searches.
Manual review of the reference sections in reviewed publications were also performed to obtain additional publications of significance.

Study Selection

The eligibility criteria for study inclusion are as follows:
(1) subjects included in the study had to be human.
(2) the study had to be written in English.
(3) the study had to evaluate the application of platelet-rich plasma, stem-cell therapy, or adipose derived products delivered under imaging guidance.
4) the study had to report on aesthetic/reconstructive applications, i.e., facial rejuvenation, scar management, treatment of alopecia, or soft tissue volumization.
The following were included as exclusionary criteria for study: non-human subjects, non-aesthetic applications, conference abstracts without the full article, and regenerative procedures without imaging guidance

Screening and Data Extraction

Two individuals completed title and abstract screening to establish relevance. Eligible studies for which it could not be determined based upon title and abstract were screened by reviewing the full paper. The authors achieved consensus when there was a difference of opinion about whether to include a study.
Relevant data from all studies included study design and patient population, method of biologic preparation, imaging modality, injection technique, clinical indication for treatment, outcome measurements, length of follow-up, and complications.

Assessment of Evidence Quality

Overall quality of evidence was assessed using the Grading of Recommendations Assessment, Development and Evaluation (GRADE) framework. Each of the three major types of therapies (platelet-rich plasma, stem-cell-based therapy, and fat grafting) was evaluated according to the following criteria for quality of evidence: Study design, risk of bias, consistency of study results, directness of the evidence, and precision with which outcome estimates are made. Results of this evaluation provided data to support comparative analyses between different types of therapies and to identify the current need for additional high-quality studies.

Ethical Use of Artificial Intelligence

Artificial intelligence–based tools were used only in the early stages of manuscript preparation for limited language checking and formatting support. All scientific content, literature selection, data interpretation, and critical analysis were performed by the authors. The final version of the manuscript was comprehensively rewritten, reviewed, and approved by the authors to ensure originality, accuracy, and full academic accountability. No AI tools were used to generate scientific arguments, fabricate data, or replace author judgment.

REGENERATIVE AESTHETICS: BIOLOGICAL BASIS

Regenerative Aesthetic Medicine is becoming increasingly popular because it addresses more than just the surface of the skin. Instead of just covering up the cosmetic effects of aging, it restores the structural integrity and biological function of the skin. While traditional approaches usually treat the visible effects of aging, such as wrinkles and sagging skin, now these techniques buff the skin and promote the growth of new skin cells and healthy connective tissue. Therefore, regenerative procedures are more physiologically based compared to traditional cosmetic procedures and therefore may provide longer-term aesthetic benefits.

As more people have sought non-surgical options for treating signs of aging, the trend has broadened to all ages. Many physicians now offer preventive and maintenance regimens (also referred to as prejuvenation) that provide patients with the opportunity to act prior to experiencing the negative effects of aging, such as wrinkle formation. Patients are choosing regenerative procedures because they prefer more natural-looking results that do not add excessive volume to the face or create unnatural contours.

The regenerative aesthetic approach includes the use of biological materials obtained from the individual patient that could repair tissue through the inclusion of cellular and molecular repair factors. Platelet-rich plasma contains the highest concentration of growth factor for stimulating fibroblast production, angiogenesis, and collagen production. Mesenchymal stem cells could support regenerative processes through both differentiation and the release of bioactive substances for regulating inflammation, increasing vascular connection, and enhancing the remodelling of the extracellular matrix. The material derived from adipose tissue contains a very large number of stromal cells, contains an extensive number of extracellular vesicles, and serves as a very durable support for tissue growth and healing.

These biological materials interact in the microenvironment where they are placed and stimulate the formation of new blood vessels, increase the dermal thickness, and improve the vitality of the cells. Growth factors produced by the platelets, including (but not limited to) platelet-derived growth factor (PDGF), vascular endothelial growth factor (VEGF) and transforming growth factor beta (TGFβ), are important for coordinating all of these processes. In addition to the production of growth factors by the platelets, the interactions of extracellular vesicles and cytokines also influence the immune response and support the dynamic process of wound healing. Therefore, the combined effect of these pathways results in an improvement of the quality of the tissue for a longer time than just the short-term volumetric effects.

Regenerative therapies are an alternative to traditional aesthetics because they focus not only on how the cell works (function) but also on how the cell is held up (structure). After treatment using biological methods, many studies have documented improved hydration, elasticity, and mechanical strength of the tissues, which correlates with improved organization of the extracellular matrix and increased blood flow to the tissues being treated. The biological basis of regenerative therapies is therefore the ideal foundation for precision delivery systems because accurate placement of a substance during the treatment will utilize the full capacity of the regenerative therapy with minimal dispersion and depletion.

IMAGING MODALITIES IN AESTHETIC INTERVENTIONS

Using imaging has become more helpful in the field of Aesthetics when using biological injectables and grafts. Imaging gives practitioners access to a true 3-dimensional look at the soft tissue layers, blood vessels, and the position of the needle relative to the skin and blood vessels as opposed to the practice of using surrounding anatomical structures, such as the nose, as a guide. Consequently, imaging provides a more accurate method of performing aesthetic procedures that ultimately improve on the safety, consistency, and clinical reproducibility of how practitioners perform the procedures.
Ultrasound imaging is currently the most popular imaging device used in the field of Aesthetic Medicine. Linear transducers with high-frequency transducers facilitate a clear visual look at the soft tissues under the skin at the face-

level, particularly the arteries, veins, and connective tissue planes. An ultrasound can provide images of the needle being advanced through the skin so that practitioners have a chance to verify the depth of their injections. Practitioners also have an ability to change the position of the needle while they are injecting materials. This is exceptionally helpful in the peri-orbital, bridge between the eyebrows(glabellar), and temples because if the needle accidentally punctures a blood vessel, it may produce serious repercussions. In addition, Doppler technology also provides clinicians with the ability to see blood flow through blood vessels. This allows for the prevention of inadvertent accidents due to a lack of blood flow to the area.

In addition to helping clinicians prevent complications, ultrasound provides the practitioner with a greater ability to ensure that materials are placed uniformly and accurately within the tissues they are injected into, leading to predictable outcomes. The accurate selection of the plane for injection can also lead to less migration of the biological materials and support for the proper integration and therapeutic activity of the grafted materials.

For procedures that require working with deeper structures or more complicated anatomical defects, advanced imaging modalities can be used as a supplementary resource. CT scanning not only gives the ability to assess osseous landmarks and deep soft tissues with high resolution but is also useful in some reconstructive or volumetric applications. MRI has advantages in soft tissue contrast and will help define a procedure plan for patients who have had prior surgery, trauma, or have developed fibrosis. However, for aesthetic procedures, both CT and MRI have limited use due to cost and availability, and with regards to CT, the risk of ionizing radiation when using CT scans.

Fluoroscopy is rarely used in aesthetic interventions but may be appropriate for use in select cases where there is a need for continuous visualization of deep tissue planes or for large-volume graft placement. Fluoroscopy is mainly limited to specialized reconstructive cases and not to routine cosmetic practices.

New imaging technologies are developing, thus increasing the capabilities of image-guided aesthetics. For example, ultrasound elastography provides a means for quantitative measurement of tissue stiffness and could help in determining the best injection planes and evaluating the degree of response associated with treatment. Furthermore, there are new imaging systems being developed based on artificial intelligence to provide automated vascular mapping and procedural planning, thereby decreasing operator variability. While these new technologies are still in the early stages of clinical integration, they are promising future tools for helping in standardizing aesthetic outcomes.

Integrating different types of imaging modalities provides a way to use a precision-based approach to improve the safety of procedures performed using these techniques, ensure consistency of delivering biologicals, and support research-based methods in the use of regenerative aesthetic medicine

PRP UNDER IMAGE GUIDANCE

Platelet Rich Plasma (PRP) is among the most frequently used biological therapies within the practice of regenerative aesthetic medicine because of its excellent safety profile, ease of preparation, availability from the individual patient (autologous), and the relatively simple process of preparation. PRP is obtained from centrifuging the peripheral blood to separate the solid components of the blood (the red blood cells and white blood cells) from the liquid component (plasma) to create a concentrated preparation of platelets, which contains a high concentration of growth factors, cytokines, and bioactive proteins. After PRP is injected into a patient, the biologically active component will be released slowly and will aid in the repair and remodelling of tissue.

The biological properties of PRP are mainly interactive with the following four types of biological mediators: Platelet-Derived Growth Factor, Vascular Endothelial Growth Factor, Transforming Growth Factor β, and Insulin-Like Growth Factor. These biological mediators stimulate fibroblast proliferation, increase the formation of new blood vessels

(angiogenesis), increase the synthesis of collagen, and mediate the inflammatory reaction. As a result, improving the texture, elasticity, and healing ability of the skin.

The conventional technique for PRP injections employs various anatomic landmarks on the skin's surface to help the physician determine where to place the needle. However, since there is no standard way to use these landmarks, the placement of PRP into the target tissues can vary and may not produce desired results. Furthermore, incorrect placement of PRP increases the chance that a blood vessel or nerve will be damaged during the procedure. One solution to these problems is utilizing imaging technology, such as ultrasound, to visualize the tissue layers and blood vessels surrounding the needle in real time. With the use of ultrasound, PRP can be accurately deposited into the appropriate tissue surface, and therefore its clinical benefits become more evident.

The use of ultrasound guidance helps to ensure that the distribution of PRP is more consistent throughout the area of injection and that there is reduced risk of injecting PRP into blood vessels. The use of Doppler imaging also allows the physician to identify the blood vessels surrounding the injection site, thus allowing for safe placement of PRP in anatomically sensitive areas. Occasionally, fluoroscopy is used to help guide PRP injection into areas that are deeper or anatomically complex; however, the routine use of fluoroscopy in an aesthetic practice is uncommon.

The clinical applications of image-guided PRP are widespread across many aesthetic practices. For example, when used for facial rejuvenation, multi-layering of intradermal and subdermal PRP has been shown to enhance skin tonality, hydration, and reduced fine line formation. In the case of androgenetic alopecia, consistent perifollicular application of PRP has been demonstrated to improve hair density and to decrease hair shedding. Additionally, the use of PRP has also been effective for the treatment of scarring, burn rehabilitation, and postoperative recovery, where PRP helps to remodel collagen and speeds up the healing process.

While numerous studies report successful outcomes with PRP therapy, there is considerable variation in protocols for preparing PRP, including differences in platelet concentration, activation, and treatment intervals. These differences preclude making direct comparisons across these studies and complicate the synthesis of evidence. Use of imaging guidance helps to lessen the impact of these limitations, as it enables a more consistent delivery method; however, further standardisation of preparation and administration procedures are still required to achieve the best clinical outcomes.

STEM-CELL THERAPIES UNDER IMAGING GUIDANCE

The use of stem cell treatments for Regenerative Aesthetics has grown in popularity because of the ability to restore biological function and structural integrity of the tissues. The two most common cellular sources for stem cell treatments include bone marrow aspirate concentrate and adipose-derived mesenchymal stem cells. Bone marrow aspirate concentrate contains mixed populations of hematopoietic and mesenchymal progenitor cells. Adipose-derived mesenchymal stem cells (ADMSCs) are accessible, plentiful, and capable of differentiating into more than one lineage. In addition to their ability to undergo differentiation, these cells also exert a significant regenerative effect by means of paracrine signalling through secretion of biologically active cytokines, growth factors, and extracellular vesicles that regulate inflammation, induce angiogenesis, and enhance the remodelling of the extracellular matrix. These mechanisms of action through paracrine signalling are believed to be the primary reasons for the therapeutic activity of stem cells in aesthetic applications. By altering the local microenvironment, stem cells are believed to improve the thickness, elasticity, and hydration of the dermis.

The accurate delivery method of cellular suspensions is crucial to the best possible achievement of effective therapeutic treatment with minimal procedural risk for patients. Traditionally, cellular suspensions have been injected into a patient based on the established landmark technique. Unfortunately, these techniques are often associated with less-than-optimal distribution of cellular suspension with a higher frequency of injury to surrounding blood vessels. Image guidance

technology has changed the ways in which cellular suspensions can be injected into a patient. Imaging techniques, most notably, ultrasound, allow for real-time observation of the injection plane and direction of the needle and nearby blood vessels, making it easier to exactly target intradermal, subcutaneous, and/or deep fascial compartments when injecting cellular suspensions and tissue.

Computed tomography is useful for supporting both deep or reconstructive applications in the case of complex or traumatic anatomical defects. In addition to offering a greater degree of procedural reproducibility, image-guided stem cell delivery may improve stem-cell survival because the appropriate tissue and blood supply are being targeted. The expected physical results of uniform distribution of the cellular suspension throughout its intended injection site include reduced localized cell aggregation and a reproducible regenerative effect. These advantages are particularly true concerning facial rejuvenation, scar remodelling, and contour restoration.

The literature on clinical outcomes of stem-cell-based aesthetic treatments is limited and of poor methodological quality. Almost all published studies are small case series, pilot trials, or observational studies that have described improved outcomes with skin texture, pigmentation, scar flexibility, and volume preservation; however, variations between the methods of isolation of the stem cells, the preparation of the stem cells, the amount of stem cells injected, and the injection technique have resulted in difficulty interpreting study results.

In addition to clinical considerations, there are also significant safety and regulatory issues associated with the use of stem cells. Reported theoretical risks are aberrant differentiation, immunodynamic responses, and potential tumor formation associated with allo-generated or heavily manipulated products. Although very few aesthetic procedures have had serious outcomes reported, there is currently insufficient data on the long-term safety of this type of treatment. Thus, a key component of proper clinical practice will include thorough screening of qualified patients for treatment, compliance with regulatory guidelines regarding stem cell use, and thoughtful communication with patients regarding the use and risks of stem cell treatments.

Overall, the use of imaging technology is vital in the goal of standardizing the delivery of stem cells for Regenerative Aesthetics. Improvements in safety and accuracy can support the development of more dependable clinical protocols for the use of stem cells and can also serve as a foundation for future, high-quality clinical studies in stem cell-based therapies.

FAT-DERIVED THERAPIES UNDER IMAGING GUIDANCE

Fat-derived therapy is at the core of the practice of Regenerative Aesthetics by allowing for the ability to restore both structural and biologically active volume back to a patient. Adipose tissue obtained from an individual has viable adipose tissue as well as stromal cells, endothelial or progenitor cells, and growth factors that will sustain tissue regeneration and integration of the graft for an extended period. Thus, fat grafting has become an acceptable method for enhancing and improving the contour, rejuvenation, and/or treatment of scarring in the face.

Low-pressure liposuction techniques and small-diameter cannulas are most used to harvest microfat (adipose tissue) while maintaining adipocyte viability and minimizing mechanical trauma. Typical donor sites for microfat harvest include the abdomen, flanks, and thighs. The harvested adipose tissue is usually harvested using decantation, filtration, or low-speed centrifugation to decrease fluid, blood, and oil content. The purified graft of adipose tissue contains a high concentration of viable adipocytes along with other extracellular matrix components and is utilized primarily to provide volume restoration to the recipient site.

Nanofat (adipose tissue): Mechanically emulsified microfat using methodically repeated transfer of microfat from one syringe to another using a filter or screen until all of the adipocytes are destroyed; maintaining the stromal cells, growth factors and extracellular matrix fragments intact. Nanofat does not provide volume and is therefore primarily used as a

dermal rejuvenator, for scar modulation, and to improve skin texture and pigment. The stromal vascular fraction (SVF) is isolated from nanofat through mechanical or enzymatic methods to isolate the regenerative cell populations (adipose derived stem cells, pericytes, endothelial cells, and immune cells). The SVF is utilized as a stand-alone product or can be used in conjunction with microfat to enhance the regenerative and volumetric effects.

The use of imaging guidance is integral to improving the outcomes achieved during both the harvest phase and injection phase of fat-related procedures. Ultrasound evaluation prior to the start of the procedure allows identification of appropriate harvest sites while avoiding damage to major vascular structures, thus decreasing complications associated with harvesting. The use of ultrasound during the injection process improves the accuracy of placement within the desired tissue layer and increases the evenness of fat distribution.

When using ultrasound guidance to view the location of the cannula and the effect of injecting on the tissue, the injector can modify their technique during the injection process and avoid applying excess pressure on the fat injected, thus decreasing the likelihood of compromising the viability of the fat being injected. The use of ultrasound reduces the chance of an intra-arterial injection of the fat; although this is infrequently seen in practice, this complication can be catastrophic, particularly in high-risk areas of the face such as the glabella, nose and temples.

From a clinical point of view, fat-derived products are commonly used to replace volume lost due to aging in the midface, peri-oral areas, jawline, and back of the hands. Nanofat and stromal vascular fraction are often used in periorbital rejuvenation, resulting in increased dermal thickness, increased dermal elasticity, and a reduction of fine lines and wrinkles. In scar management, fat-derived therapies have demonstrated increased fibroblast activity, increased collagen production, and improved tissue pliability, resulting in improved cosmetic outcomes.

While many clinical studies have demonstrated the efficacy of fat grafting, the retention of grafts can be inconsistent based on the method of fat harvesting, how fat is processed and injected, and how well the area receiving the graft has blood flow. By using imaging as guidance when grafting fat, one can achieve better reproducibility and potentially increase the survival of the graft because tissue will grow into and integrate with the grafted tissue better. However, standardised protocols and long-term clinical outcome evaluations will help clarify the best practice for using fat grafts in the clinical setting.

COMPARATIVE ANALYSIS

Three main types of biological therapies are available in regenerative aesthetic medicine: Platelet Rich Plasma (PRP), stem cell treatments and fat grafts (called adipose grafts). While these three methods have the same purpose of improving the regeneration of tissue and the aesthetic appearance of the client, each one has its own unique mechanisms of action, uses, amount of scientific support for use and level of safety. Therefore, a direct comparison of all three forms of therapy is necessary for informed decision making by clinicians and responsible advice to clients about the option best suited to their needs.

PRP has its greatest regenerative effect through the delivery of various growth factors that initiate angiogenesis, stimulate fibroblast production, facilitate the maturation of scar tissue through the production of extracellular matrix (ECM) components, and stimulate the production of collagen. Because PRP is harvested from the client's own body, with minimal processing needed prior to use, it has a much lower risk for side effects, making it an attractive option for many aesthetic professionals. PRP has demonstrated efficacy in facial rejuvenation, treating male-pattern baldness, reducing the appearance of scars and increasing the longevity of fat grafts. However, the effects of PRP therapy are variable and may require multiple sessions to maintain optimal results.

Stem cell treatments, on the other hand, support the regeneration of tissue through two mechanisms: differentiation of mesenchymal cells into specialized connective tissue cells (so-called "untargeted metabolism") and cell-signalling pathways ("paracrine signalling"). Adipose-derived stem cells (ASCs) and bone marrow-derived MSCs (MSCs) modulate the inflammatory response, promote angiogenesis (formation of new blood vessels), and support tissue remodelling. Positive results for using stem cells in the areas of facial rejuvenation and scar remodelling have been reported in the literature; however, most of the literature supporting the use of stem cells comes from small observational trials. In addition, the lack of regulatory approval for most stem-cell-based treatments and the uncertainty of long-term safety may limit the use of these therapies in clinical practice at this time.

Autologous fat grafting produces both immediacy of volume and durability of regenerative benefits through the introduction of both stromal cells and growth factors. It is commonly used for facial contouring, rejuvenation of the hands, and correction of scars; however, while there is a large clinical experience to support the use of fat grafting, the retention of fat is difficult to predict and complications such as fat necrosis and the formation of oil cysts can happen. Studies have demonstrated that using imaging technology for guidance improves accuracy in placement and reduces the risks of vascular events, making fat grafting safer than it was previously thought to be. When considering the available evidence for PRP, levels of confidence are based on a low to moderate quality of evidence, especially in association with evidence-based applications such as alopecia and skin rejuvenation. Evidence of the efficacy of stem-cell therapy is of low to very low quality, due to the limited number of clinical trials and the wide range of methodology and approaches to carrying out trials. In general, fat grafting has a moderate amount of observational evidence in support of its use; however, very few high-quality randomised trials exist. For all modalities of treatment examined, the delivery of tissue in an image-guided manner produces increased consistency in terms of technical success and decreased overall rates of complications compared to non-image guided delivery methods.

Table 1. Comparative Characteristics of Regenerative Aesthetic Modalities

Parameter	Platelet-Rich Plasma	Stem-Cell Therapy	Fat-Derived Therapy
Primary mechanism	Growth factor–mediated tissue repair	Cellular differentiation and paracrine signaling	Volumetric support and stromal regeneration
Common indications	Facial rejuvenation, alopecia, scars	Rejuvenation, scar remodeling, reconstruction	Volumization, contouring, scars
Biologic source	Autologous blood	Bone marrow or adipose tissue	Autologous adipose tissue
Evidence quality (GRADE)	Low to moderate	Low to very low	Moderate
Durability	Variable: repeat sessions needed	Uncertain; limited long-term data	Variable; dependent on graft survival
Main risks	Bruising, edema, limited response	Regulatory, theoretical tumor risk	Fat necrosis, embolism (rare)
Regulatory status	Generally permissive	Highly restricted	Moderate regulation
Role of imaging	Improves precision and safety	Enhances placement and viability	Reduces vascular risk, improves retention

SAFETY AND COMPLICATIONS

Regenerative aesthetic procedures involve placing materials that are biologically active into parts of the body that are complicated in both anatomic structure and have numerous blood vessels. When a procedure is performed using anatomical landmarks and without real-time monitoring, there is a risk that a substance will not be put in the correct location, that the substance will not be dispersed evenly in the tissue, and that there will be damage to blood vessels. These limitations could impair the effectiveness of the treatment and increase the risk of developing an adverse event.
A serious potential complication associated with facial injectables is that they could inadvertently enter a blood vessel (inadvertent intravascular injection). Vascular occlusion from injection of a filler material into a high-risk area (periorbital, glabellar, nasal, and temporal regions) can cause tissue to Ischemic (lack of oxygen) and/or necrotic (dead), resulting in irreversible loss of vision. Grafting fat without a means of guided imaging also has been implicated in fat embolism and central retinal artery occlusion. Although these events are infrequent, their potential for serious consequences emphasizes the need for accuracy-based delivery.

Platelet-Rich Plasma (PRP) is thought to have a safe profile because it is derived from the patient's own blood and, therefore, is minimally manipulated. Common complications reported with the use of PRP are mild and of short duration, i.e., local pain, edema, redness, and bruising. Serious complications have been reported infrequently and are usually associated with technical errors rather than the biological properties of PRP itself.

The use of stem cell therapy adds an additional level of concern from a safety standpoint. As the use of stem cells is relatively new, safety needs to be carefully considered, and there are numerous theoretical risks regarding the implementation of stem cells, including the ability of stem cells to differentiate inappropriately, cause immunologic reactions and potentially lead to the development of tumors or cancer, especially when there is extensive manipulation of stem cells or if stem cells are obtained from other individuals (i.e. Allogeneic). There has been a limited number of reported adverse events related to aesthetic applications, and as such, the lack of large-scale and long-term safety data also creates a significant concern. It is therefore important to follow the regulations related to the use of stem cells strictly and to perform appropriate patient selection.

With the application of fat-derived therapies, there is the potential for local and systemic complications. The most common complications associated with fat-derived therapies include fat necrosis, oil cysts, contour irregularities, and infection. There is also the potential for graft resorption and Volume Asymmetry followed by secondary procedures. Although these are rare, there are serious complications associated with the use of fat-derived therapies, including the possibility of fat embolism and vascular occlusion, which are typically associated with high-pressure injection or intravenous placement of a cannula.

The use of imaging to guide the procedure significantly reduces procedural risk by allowing the clinician to visualize the anatomy of the vascular system, the trajectory of the needle, and the tissue response in real-time. The use of ultrasound imaging allows the clinician to avoid important blood vessels, confirm the correct injection plane, and confirm an even distribution of the graft. In addition, Doppler imaging allows the clinician to see the areas where blood is actively flowing and increases safety. With the use of imaging, the clinician can also identify early on complications such as hematoma formation, fluid collections, and fluid displacement, allowing for early intervention.

Clinical studies and procedural audits suggest that ultrasound-guided regenerative interventions are associated with lower complication rates and improved outcome predictability compared with blind techniques. Although imaging guidance does not eliminate risk entirely, it represents a critical component of modern safety protocols in regenerative aesthetic practice.

REGULATORY AND ETHICAL CONSIDERATIONS

The clinical application of regenerative biologic therapies in aesthetic medicine is governed by complex and evolving regulatory frameworks that vary considerably across jurisdictions. These regulations are designed to balance innovation with patient safety, scientific integrity, and ethical responsibility. Understanding and complying with these frameworks is essential for clinicians practicing imaging-guided regenerative aesthetics.

Because PRP is usually minimally manipulated autologous product under the definition established for regulation by the FDA, PRP is therefore subject to relatively little or limited regulatory restrictions in many jurisdictions. PRP can be used by physicians in the U.S. and in many European countries for homologous purposes when manufactured with approved preparation devices and within an approved clinical governance structure.

In many parts of South Asia, clinicians direct the use of PRP; however, there is a recommendation that any new or testing application of PRP receive institutional ethical approval. On the contrary, stem cell therapy is highly regulated with strict oversight because the long-term safety, immunogenicity and tumorigenicity of stem cell therapies are currently uncertain. Under 21CFR 1271, most stem cell products are classified as human cells, tissues and cellular products, therefore requiring the sponsoring organization to obtain FDA authorization before the implementation of substantially manipulated, or non-homologous, stem cell products in clinical trials. In Europe, stem cell therapies are classified as Advanced Therapy Medicinal Products and require a centralized regulatory approval process. According to the Indian regulatory framework, there is also a regulation restricting the use of stem cells for non-homologous aesthetic purposes, and these therapies require oversight by an institutional ethics committee before being approved for human use.

The extent of manipulation of the tissue is the primary determining factor for the regulation of fat-derived therapies. Most regions allow autologous fat grafting with minimal mechanical processing for aesthetic purposes; however, the enzymatically isolated stromal vascular fraction is classified as more than minimally manipulated tissue and, as such, is subject to stricter regulations. Within India specifically, utilization of stromal vascular fraction can only occur under investigational purview after receiving ethics committee approval and notifying the regulatory body.

Regenerative aesthetics holds itself to the ethical principles surrounding ethical practice, which are autonomy, beneficence, non-maleficence and justice. Clinicians involved in regenerative aesthetics have an obligation to inform patients thoroughly and accurately in regard to the appropriate indications for treatment, the expected therapeutic outcomes, the risk of adverse effects associated with the various procedures, as well as informing them of the limitations present in their scientific knowledge at the time they receive treatment, specifically noting that it may be investigational in nature for the stem cell-based therapies.

Regenerative aesthetics: Ethical oversight of marketing and promotional practices. Inaccurate/exaggerated marketing claims, selective reporting of treatment outcome data, and/or misrepresentation of independent peer-reviewed published scientific studies all negatively impact patient confidence in the clinician and the integrity of the practitioner.

Clinicians have an obligation to address the financial burden of regenerative aesthetic procedures through price equity and responsible resource utilization. To support patient safety, facilitate outcome monitoring, and develop high quality clinical evidence, institutional ethics reviews, standardised documentation, and structured long-term follow up must be part of the ethics governance processes. As regenerative aesthetic medicine continues to develop; ongoing collaboration between clinicians, regulators, and bioethicists must be found to ensure responsible and transparent clinical practice.

FUTURE DIRECTIONS

Regenerative aesthetic medicine has made significant progress in recent years, however there are still many scientific, technical, and regulatory challenges to address prior to mainstreaming these therapies into standardized clinical practice. A major concern is that there is currently no harmonized global regulatory framework. Differences in approval process and oversight have resulted in a proliferation of unregulated and/or inadequately monitored practices, such as "stem-cell tourism" which pose serious clinical and ethical risks to patients.

Thus, for regenerative aesthetics to progress in the future, it will be necessary to develop combined regulatory processes which promote patient safety while encouraging responsible innovation. Collaboration between international regulatory agencies, professional societies, and academic institutions may help create common standards for the processing of biologics, the application of biologics to patients, and the reporting of patient outcomes.

Technological innovations are expected to become an increasingly important factor in regenerative aesthetics. New techniques such as ultrasound, three-dimensional imaging, and AI assistance for pre-procedural planning will likely enable greater accuracy in parameters such as vascular mapping, injection techniques, and operator variability. As robotic-assisted techniques are developed in the future, it is likely that they will also allow for increased procedural accuracy in specific situations. Nonetheless, when integrating these new technologies, it is critical that robust governance frameworks addressing issues such as data security, algorithmic transparency, and accountability for professionals are in place.

A major gap in research is the current lack of multicenter randomized controlled trials (RCTs) with sufficient patient numbers and long-term follow-up that provide a high level of evidence. The need for standardization across biologically based treatments (e.g., biotherapeutics) through uniform imaging procedures, dosing regimens, and assessment tools is crucial for minimizing variability across studies and improving the quality of research quality assessments. Creating and validating patient-reported outcome measures (PROMs) for regenerative aesthetics is a means to enhance the clinical evaluation of patients treated with regenerative therapies.

The future of this area of medicine relies heavily upon and will continue to benefit from developing inter-professional teams (IPTs). Establishing IPTs that incorporate all of the involved specialties; interventional radiology, dermatology, plastic surgery, regenerative medicine, and bioethics will ease the pathway to developing standard treatment guidelines and structured training programs. Their existence may facilitate the establishment of accredited centers of excellence that provide a consistent standard of care.

Although it is unclear which existing IPT will emerge with similar scientific credibility as the developing regenerative aesthetic field, scientific rigor, technological advances, and ethical oversight will assure that regenerative aesthetic medicine is constructed as a sound, evidence-based discipline. Long-term investments in clinical research, education, and regulatory harmonization will be critical for promoting sustainable and highly responsible progress within regenerative aesthetic medicine.

CONCLUSION

Regenerative aesthetics stands as a primary development in aesthetic medicine where practices have moved from temporary cosmetic enhancement to biologically based restoration of tissue and long-term rejuvenation. The use of autologous biologics (the patient's own body), such as platelet-rich plasma (PRP), stem cell-based therapies, and fat grafting, illustrates the shift in focus from short term cosmetic improvement to the restoration of tissue quality, integrity (structure), and function (physiological performance).

The incorporation of interventional radiology has helped to resolve one of the major limitations of most conventional aesthetic procedures, the reliance on operator-dependent landmark-based injection techniques. By using real-time imaging guidance (especially with ultrasound), physicians can visualize the blood vessels and tissue structures they are injecting in real-time, which increases the accuracy and reproducibility of their procedures, and helps to decrease the incidence of serious complications. Accurate selection of tissue plane, in combination with accurate delivery, also enhances the survival of grafts and increases the potential for more consistent clinical results.

Presently available information indicates that the delivery of active ingredients using imaging guidance (e.g., ultrasound) provides safety and technical advantages in all areas of regenerative medicine. Platelet-rich plasma is considered to have good tolerability and provides moderate clinical benefits when used in certain indications. Stem cell therapies have shown promise, although the limitations of the studies conducted so far have resulted in insufficient high-quality evidence to support long-term safety and efficacy. Fat-derived therapies produce volume increase and regeneration but have not consistently demonstrated sufficient graft retention durability across various practices. Each type of therapy should implement imaging guidance to help maximize its therapeutic potential while minimizing risk during the procedure.

However, the heterogeneity in the methods used to produce biologics, administer them, and evaluate the outcomes remains a significant barrier to the widespread adoption of regenerative aesthetic practices. This, combined with the lack of large-scale randomized controlled trials and tools that standardize the evaluation of outcomes, has limited our capability to definitively assess the long-term efficacy of these products. Regulatory variances and ethical issues emphasize the necessity for transparent regulatory structures and responsible clinical application.

Combining techniques from both regenerative medicine and interventional radiology will create an avenue to provide more precise treatments with less risk, more predictability and better biological outcomes in aesthetics. Collaboration between different specialties, clinical trials, and standardized education will help in establishing the standard of care for regenerative aesthetic imaging-guided procedures so they can continue to be offered and grow sustainably over time.

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