Advances in the Treatment of Atrophic Acne Scars: Lasers, Radiofrequency, Microneedling, Subcision, and Regenerative Approaches

Amani Nassar, Nawal Shohdy, Norhan Hassan

Dermatology, Venereology and Andrology, Faculty of Medicne, Zagazig University

Corresponding Author: Nawal Shohdy

Received: 28 October 2024, **Accepted:** 17 November 2024, **Published:** 20 November 2024

Abstract

Background: Acne vulgaris is a highly prevalent inflammatory skin disorder that frequently results in permanent scarring, particularly in moderate-to-severe cases. Atrophic acne scars, including ice-pick, boxcar, and rolling types, represent the most common and therapeutically challenging sequelae. These scars are associated with significant psychosocial distress, impaired quality of life, and long-term cosmetic dissatisfaction. Over the past two decades, substantial advances have been made in procedural dermatology, leading to the development of multiple energy-based devices, minimally invasive techniques, and regenerative therapies aimed at improving scar texture and appearance. However, the heterogeneity of scar morphology, skin phototypes, and patient expectations necessitates a tailored, evidence-based treatment approach.

Aim: This review aims to comprehensively evaluate current and emerging treatment modalities for atrophic acne scars, including laser technologies, radiofrequency devices, microneedling techniques, subcision methods, injectable fillers, and regenerative approaches such as platelet-rich plasma. Emphasis is placed on understanding the mechanisms of action, clinical efficacy, safety profiles, and appropriate patient selection for each modality. Additionally, the review highlights the growing role of combination therapies and phenotype-directed treatment algorithms to optimize clinical outcomes.

Conclusions: The management of atrophic acne scars has evolved from single-modality interventions to sophisticated, multimodal strategies grounded in scar morphology and pathophysiology. Fractional lasers, radiofrequency, microneedling, and subcision remain foundational techniques, while regenerative therapies offer promising adjunctive benefits through enhanced collagen remodeling and wound healing. Combination treatments consistently demonstrate superior outcomes compared with monotherapy, particularly for moderate-to-severe scarring. Despite these advances, challenges remain in standardizing outcome measures, minimizing adverse effects—especially in darker skin phototypes—and identifying optimal treatment sequencing. Future research should focus on high-quality comparative trials, objective assessment tools, and personalized regenerative approaches to further refine acne scar management and improve patient-centered outcomes.

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Keywords: *Atrophic Acne Scars, Treatment*

Introduction

Acne vulgaris is one of the most prevalent chronic inflammatory skin diseases worldwide, affecting up to 85% of adolescents and a substantial proportion of adults. Although active acne lesions may resolve, permanent scarring develops in a significant number of patients, even in cases previously classified as mild or moderate. Atrophic acne scars—characterized by dermal collagen loss and architectural distortion—are the most common subtype and include ice-pick, boxcar, and rolling scars. These scars represent a visible and often lifelong consequence of acne-related inflammation, reflecting both the intensity and duration of the inflammatory process as well as individual wound-healing responses [1,2].

Beyond their physical appearance, atrophic acne scars exert a profound psychosocial burden. Multiple studies have demonstrated associations between acne scarring and reduced self-esteem, social withdrawal, anxiety, depression, and impaired quality of life, sometimes exceeding the psychological impact of active acne itself. Because scars are typically located on cosmetically sensitive areas such as the face, they may affect interpersonal relationships, occupational opportunities, and overall psychological well-being. Consequently, the effective management of acne scarring is not merely cosmetic but represents an important component of comprehensive dermatologic care [3,4].

From a pathophysiologic standpoint, atrophic acne scars arise from an imbalance between collagen degradation and synthesis during the resolution phase of acne inflammation. Excessive matrix metalloproteinase activity, persistent perifollicular inflammation, and impaired fibroblast-mediated neocollagenesis contribute to dermal thinning and tethering of the skin to underlying structures. This complex pathogenesis explains why topical therapies alone are ineffective and why procedural interventions aimed at stimulating collagen remodeling or mechanically releasing fibrotic bands are required for meaningful clinical improvement [5,6].

Over the past two decades, the therapeutic landscape for atrophic acne scars has expanded considerably. Traditional modalities such as ablative laser resurfacing have been complemented—and in some cases supplanted—by fractional lasers, radiofrequency-based devices, microneedling techniques, subcision, injectable fillers, and regenerative approaches including platelet-rich plasma. While these advances have improved safety profiles and broadened treatment options across different skin phototypes, no single modality is universally effective. A major research gap remains in defining optimal treatment selection, sequencing, and combination strategies based on scar morphology and patient-specific factors. This review aims to synthesize current evidence on established and emerging therapies for atrophic acne scars, with a focus on mechanism-based treatment selection and clinically relevant outcomes [7–9].

Pathophysiology of Atrophic Acne Scarring

Atrophic acne scars develop as a consequence of dysregulated wound healing following inflammatory acne lesions. The initial insult is driven by follicular rupture and the subsequent release of keratin, sebum, and *Cutibacterium acnes* antigens into the dermis, triggering an intense inflammatory response. Pro-inflammatory cytokines such as interleukin (IL)-1β, IL-6, and tumor necrosis factor-α amplify local tissue injury, leading to destruction of dermal collagen and elastin. When inflammation is prolonged or recurrent, the reparative process becomes insufficient, resulting in permanent loss of dermal volume and surface depressions characteristic of atrophic scars [10,11].

A central mechanism in scar formation is the imbalance between matrix degradation and synthesis. During active inflammation, increased expression of matrix metalloproteinases (MMPs), particularly MMP-1 and MMP-9, leads to excessive breakdown of type I and III collagen. In parallel, tissue inhibitors of metalloproteinases are relatively underexpressed, further favoring net collagen loss. This proteolytic environment disrupts the normal extracellular matrix scaffold, impairing proper dermal regeneration and predisposing to scar depression rather than restitution of normal skin architecture [12,13].

Fibroblast dysfunction plays a pivotal role in the evolution of atrophic scars. In contrast to hypertrophic or keloid scarring, where fibroblast hyperactivity predominates, atrophic acne scars are associated with reduced fibroblast proliferation and diminished collagen production. Transforming growth factor-β signaling, a key regulator of wound healing and collagen synthesis, appears attenuated in atrophic scarring,

resulting in inadequate neocollagenesis. This impaired cellular response explains why therapeutic strategies aimed at stimulating fibroblast activity—such as energy-based devices and microneedling—are central to modern acne scar management [14,15].

The depth and morphology of atrophic scars are also influenced by mechanical factors within the dermis. Fibrotic strands tether the epidermis to deeper structures, particularly in rolling scars, preventing elevation of the skin surface even when collagen remodeling occurs. These fibrous septae form during the chronic inflammatory phase and contribute to the persistence of scars over time. Their presence underlies the rationale for subcision techniques, which mechanically disrupt these attachments to allow dermal lifting and subsequent collagen deposition during healing [16,17].

Individual patient factors further modulate scar development. Genetic predisposition, severity and duration of inflammatory acne, delayed or inadequate treatment of active lesions, and repeated mechanical trauma such as picking or squeezing all increase the risk of atrophic scarring. Additionally, skin phototype influences post-inflammatory responses and the risk of dyspigmentation following procedural interventions, although it does not directly alter the fundamental mechanisms of collagen loss. Understanding these pathophysiologic processes provides the foundation for a morphology-driven, multimodal approach to the treatment of atrophic acne scars [18,19].

Clinical Classification of Atrophic Acne Scars

Accurate clinical classification of atrophic acne scars is fundamental to successful treatment planning, as scar morphology strongly predicts response to specific therapeutic modalities. Atrophic scars result from net loss of dermal collagen and are traditionally divided into three principal subtypes: ice-pick, boxcar, and rolling scars. Most patients present with a combination of these scar types, underscoring the need for individualized and multimodal treatment strategies rather than a single uniform approach [20,21].

Ice-pick scars are narrow (<2 mm), deep, and sharply marginated depressions that extend vertically into the deep dermis or subcutaneous tissue. They are often described as appearing as if the skin has been punctured by a sharp instrument. Because of their depth and limited surface area, ice-pick scars respond poorly to resurfacing techniques alone. Instead, focal destructive or reconstructive approaches such as chemical reconstruction of skin scars (CROSS), punch excision, or punch elevation are typically required. Their resistance to conventional modalities highlights the importance of precise scar typing prior to initiating treatment [22,23].

Boxcar scars are round or oval depressions with well-defined vertical edges and a flat base. They may be shallow or deep and are commonly found on the cheeks and temples. Shallow boxcar scars can respond favorably to fractional laser resurfacing, radiofrequency, or microneedling, whereas deeper boxcar scars often require combination approaches, including subcision or filler augmentation. The sharply demarcated margins of boxcar scars allow for measurable improvement with collagen-stimulating procedures, particularly when epidermal resurfacing is combined with dermal remodeling techniques [24,25].

Rolling scars are characterized by broad (>4–5 mm), shallow depressions with sloping edges that create an undulating skin surface. These scars are caused by fibrous bands tethering the dermis to the underlying subcutaneous tissue, making them particularly amenable to subcision. Energy-based devices and microneedling alone are often insufficient unless the mechanical tethering is first released. Rolling scars typically demonstrate the most dramatic improvement when subcision is combined with fillers, radiofrequency, or laser-based treatments [26,27].

In clinical practice, mixed-pattern scarring is the rule rather than the exception. Comprehensive scar assessment should therefore include evaluation of scar type, depth, distribution, and associated textural or pigmentary changes. Several grading systems, including qualitative and quantitative scales, have been proposed to standardize assessment, but none has achieved universal adoption. Nevertheless, morphology-based classification remains the cornerstone of evidence-based acne scar management and serves as the foundation for modern combination treatment algorithms [28,29].

Principles of Treatment Selection

The successful management of atrophic acne scars relies on a structured, individualized treatment strategy rather than a single-modality approach. Given the heterogeneity of scar morphology, depth, and

distribution, treatment selection must be guided primarily by clinical scar type, with additional consideration of patient-specific factors. Ice-pick scars, deep boxcar scars, and rolling scars differ substantially in their underlying pathology and therefore require distinct therapeutic interventions. Failure to tailor treatment to scar morphology is a major cause of suboptimal outcomes and patient dissatisfaction [30,31].

Scar depth and dermal involvement are critical determinants of procedural choice. Superficial atrophic scars may respond adequately to collagen-stimulating modalities such as microneedling, non-ablative fractional lasers, or radiofrequency devices. In contrast, deeper scars extending into the reticular dermis or subcutaneous tissue typically require more aggressive or combination approaches, including ablative lasers, subcision, or filler augmentation. Accurate assessment using oblique lighting, skin stretching, and palpation is essential to distinguish tethered scars from purely textural irregularities [32,33].

Skin phototype plays a pivotal role in treatment planning, particularly when energy-based devices are considered. Patients with higher Fitzpatrick skin types are at increased risk of post-inflammatory hyperpigmentation and, less commonly, scarring following aggressive resurfacing procedures. Consequently, non-ablative lasers, fractional radiofrequency, and microneedling are often preferred in darker skin types due to their more favorable safety profiles. Pre-treatment priming, conservative energy settings, and strict photoprotection are essential components of risk mitigation in these populations [34,35].

Patient expectations, tolerance for downtime, and willingness to undergo multiple treatment sessions must also be incorporated into the decision-making process. While ablative laser resurfacing may yield substantial improvement in a single session, it is associated with prolonged recovery and higher risk of adverse effects. Conversely, minimally invasive procedures typically require multiple sessions to achieve comparable results but offer shorter downtime and greater safety. Clear pre-procedural counseling regarding realistic outcomes—often improvement rather than complete resolution—is crucial to achieving patient satisfaction [36,37].

Increasing evidence supports the superiority of combination therapy over monotherapy for moderate-to-severe atrophic acne scarring. Combining techniques that address different pathogenic mechanisms—such as subcision for fibrotic tethering, energy-based devices for collagen remodeling, and fillers or regenerative therapies for volume restoration—results in additive or synergistic clinical improvement. However, standardized treatment algorithms and high-quality comparative trials remain limited, representing an important gap in the current literature. A rational, phenotype-directed and patient-centered approach therefore remains the cornerstone of contemporary acne scar management [38,39].

Ablative Laser Therapies

Ablative laser resurfacing has historically represented one of the most effective treatment modalities for moderate-to-severe atrophic acne scars due to its ability to induce controlled epidermal and dermal injury, leading to robust collagen remodeling. Carbon dioxide (CO_2) and erbium-doped yttrium aluminum garnet (Er:YAG) lasers are the most commonly used ablative devices. These lasers work by vaporizing tissue and creating a wound-healing response characterized by neocollagenesis, elastin reorganization, and epidermal regeneration. Early studies demonstrated significant clinical improvement in scar depth and texture, establishing ablative lasers as a benchmark for acne scar treatment efficacy [40,41].

The CO_2 laser emits light at a wavelength of 10,600 nm, which is strongly absorbed by water, allowing for deep tissue ablation and coagulation. This depth of penetration facilitates substantial collagen contraction and long-term remodeling, making CO_2 lasers particularly effective for deep boxcar and rolling scars. However, this benefit is offset by a higher risk of adverse effects, including prolonged erythema, infection, scarring, and post-inflammatory hyperpigmentation, especially in patients with darker skin phototypes. These limitations have led to a decline in traditional fully ablative CO_2 resurfacing in favor of fractional approaches [42,43].

Er:YAG lasers, operating at a wavelength of 2,940 nm, exhibit even greater water absorption with more precise ablation and minimal thermal damage to surrounding tissue. As a result, Er:YAG resurfacing is associated with faster re-epithelialization and reduced downtime compared with CO_2 lasers, albeit with somewhat less collagen contraction. Clinical outcomes are generally favorable for superficial to moderate

atrophic scars, but deeper scars may require multiple sessions or adjunctive procedures to achieve optimal results [44,45].

The introduction of fractional ablative laser technology marked a significant advance by combining the efficacy of ablative resurfacing with improved safety. Fractional CO_2 and fractional Er:YAG lasers create microscopic columns of thermal injury surrounded by intact tissue, promoting rapid healing while stimulating dermal remodeling. Multiple studies have demonstrated meaningful improvement in acne scar severity with fractional ablative lasers, along with reduced downtime and a lower incidence of complications compared with traditional ablative resurfacing [46,47].

Despite their proven efficacy, ablative laser therapies require careful patient selection and meticulous peri-procedural management. Pre-treatment priming, antiviral prophylaxis when indicated, and strict post-treatment photoprotection are essential to minimize complications. While ablative lasers remain a powerful tool in acne scar revision, their role has evolved toward integration within multimodal treatment plans rather than standalone therapy, particularly in patients with mixed scar types or higher pigmentary risk [48,49].

Non-Ablative Laser Therapies

Non-ablative laser technologies were developed to stimulate dermal collagen remodeling while preserving the integrity of the epidermis, thereby reducing downtime and procedural risk compared with ablative resurfacing. These devices deliver controlled thermal energy to the dermis, inducing fibroblast activation and neocollagenesis without tissue vaporization. As a result, non-ablative lasers have become widely adopted for patients with mild-to-moderate atrophic acne scars, those seeking minimal recovery time, and individuals with higher Fitzpatrick skin phototypes [50,51].

Commonly used non-ablative fractional lasers include 1,320-nm and 1,450-nm diode lasers, 1,540-nm erbium:glass lasers, and 1,550-nm erbium-doped fiber lasers. These wavelengths target dermal water to create microthermal zones that stimulate collagen production while sparing surrounding tissue. Clinical studies have demonstrated gradual but consistent improvement in scar texture, depth, and overall skin quality following multiple treatment sessions. Although the degree of improvement is generally less dramatic than that seen with ablative lasers, the favorable safety profile makes non-ablative devices an attractive option for many patients [52,53].

Fractional photothermolysis represents a key technological advancement within non-ablative laser therapy. By delivering energy in a pixelated pattern, fractional lasers allow for rapid epidermal recovery and reduced risk of adverse effects such as infection or prolonged erythema. Histologic studies have confirmed increased dermal collagen and elastin deposition following treatment, supporting their mechanism of action. Clinically, non-ablative fractional lasers are particularly effective for shallow boxcar scars and superficial rolling scars when used in a series of sessions [54,55].

One of the principal advantages of non-ablative laser therapies is their suitability for darker skin phototypes, in whom the risk of post-inflammatory hyperpigmentation is a major concern. While pigmentary alterations can still occur, the incidence and severity are significantly lower than with ablative resurfacing when appropriate parameters and cooling techniques are employed. This expanded safety margin has allowed for broader application of laser scar treatments across diverse patient populations [56,57].

Despite these benefits, non-ablative lasers have inherent limitations. Deep ice-pick scars and significantly tethered rolling scars respond poorly to non-ablative laser monotherapy, highlighting the need for adjunctive treatments such as subcision or chemical reconstruction techniques. Current evidence increasingly supports the use of non-ablative lasers as part of combination regimens rather than standalone therapy. Continued research is needed to optimize treatment parameters, session intervals, and combination strategies to maximize clinical outcomes while maintaining safety [58,59].

Fractional Radiofrequency Devices

Fractional radiofrequency (RF) devices have emerged as an important modality in the treatment of atrophic acne scars by delivering controlled thermal energy to the dermis independent of chromophore absorption. Unlike laser-based technologies, RF energy is not dependent on melanin or water as a target, which allows

for more uniform dermal heating across different skin phototypes. This characteristic makes fractional RF particularly advantageous in patients with darker skin, in whom the risk of pigmentary complications from laser treatments is higher [60,61].

Fractional RF systems can be broadly categorized into non-invasive and microneedle-based devices. Non-invasive RF devices deliver energy through the epidermis to induce dermal heating and collagen denaturation, followed by neocollagenesis during wound healing. While these devices are associated with minimal downtime and a favorable safety profile, their depth of penetration is limited, and clinical improvement in acne scarring is generally modest. Consequently, they are most effective for mild atrophic scars or as adjuncts to other procedures [62,63].

Microneedle radiofrequency devices represent a significant advancement by combining mechanical dermal penetration with targeted RF energy delivery. Insulated or non-insulated microneedles are inserted into the dermis, allowing RF energy to be deposited at precise depths while minimizing epidermal damage. This targeted approach promotes collagen remodeling, elastin formation, and dermal thickening, making microneedle RF particularly effective for rolling and boxcar scars. Multiple clinical studies have demonstrated significant improvement in scar severity, texture, and patient satisfaction following a series of treatments [64,65].

Histologic evaluations following microneedle RF treatment have confirmed increased collagen density, enhanced elastic fiber organization, and dermal remodeling without disruption of the epidermal barrier. These findings correlate with clinical improvements observed over several months, reflecting the gradual nature of collagen regeneration. Adverse effects are generally mild and transient, including erythema, edema, and pinpoint bleeding, with a low incidence of post-inflammatory hyperpigmentation when appropriate parameters are used [66,67].

Despite its advantages, fractional RF is not universally effective as monotherapy for all scar types. Deep ice-pick scars and severely tethered rolling scars often require additional interventions such as subcision or focal reconstructive techniques. Current evidence supports the integration of fractional RF into combination treatment protocols, where it complements other modalities by enhancing collagen remodeling and improving overall skin texture. As technology continues to evolve, further studies are needed to refine treatment parameters, optimize needle design, and establish standardized protocols for acne scar management [68,69].

Microneedling Techniques

Microneedling has gained widespread acceptance as a minimally invasive and cost-effective treatment option for atrophic acne scars due to its ability to induce controlled dermal injury and subsequent collagen remodeling. The technique involves the use of fine needles to create multiple microchannels in the skin, triggering a wound-healing cascade characterized by platelet activation, growth factor release, and fibroblast proliferation. Unlike energy-based devices, microneedling preserves the epidermis, resulting in a favorable safety profile and minimal downtime [70,71].

Conventional microneedling is typically performed using dermarollers or manual needling devices with fixed needle lengths. These tools are effective for superficial to moderate atrophic scars, particularly shallow boxcar and rolling scars. Clinical studies have demonstrated gradual improvement in scar depth, skin texture, and overall appearance after multiple treatment sessions spaced several weeks apart. The efficacy of microneedling is highly dependent on needle depth, treatment frequency, and operator technique, underscoring the importance of standardized protocols [72,73].

Automated microneedling pens represent a technological refinement that allows for precise control of needle depth, speed, and penetration angle. This improved precision enhances reproducibility and enables treatment of scars at varying dermal depths within the same session. Automated devices have been shown to produce more uniform collagen induction compared with manual techniques and are associated with high patient satisfaction. Their adaptability makes them particularly suitable for combination therapies with topical agents or energy-based modalities [74,75].

Histopathologic studies following microneedling reveal increased deposition of type I and III collagen, thickening of the papillary dermis, and reorganization of elastin fibers. These changes occur gradually

over several months, which explains the progressive improvement in scar appearance observed clinically. Adverse effects are generally mild and transient, consisting mainly of erythema, edema, and pinpoint bleeding. The risk of post-inflammatory hyperpigmentation is low, making microneedling a valuable option for patients with higher Fitzpatrick skin phototypes [76,77].

Despite its advantages, microneedling has limitations when used as monotherapy for severe atrophic acne scars. Deep ice-pick scars and scars with significant fibrotic tethering respond poorly unless adjunctive treatments such as subcision or chemical reconstruction are employed. Increasing evidence supports the use of microneedling in combination with platelet-rich plasma, radiofrequency, or fractional lasers to enhance clinical outcomes. As part of a multimodal treatment strategy, microneedling plays an important role in contemporary acne scar management [78,79].

Subcision Techniques

Subcision is a cornerstone technique in the management of atrophic acne scars, particularly rolling scars, as it directly addresses one of the fundamental pathophysiologic mechanisms: fibrotic dermal tethering. The procedure involves the insertion of a needle or cannula into the deep dermis or subcutaneous plane to mechanically sever fibrous strands that anchor the scar base to underlying tissues. Release of these fibrotic attachments allows elevation of the depressed scar and initiates a wound-healing response that promotes new connective tissue formation [80,81].

Traditional subcision is commonly performed using hypodermic needles, such as Nokor or tri-beveled needles, which facilitate effective cutting of fibrous bands. The procedure is typically conducted under local anesthesia and may be accompanied by immediate improvement in scar appearance due to tissue release and controlled hematoma formation. Over subsequent weeks, the organized repair process contributes to further dermal thickening and scar elevation. Clinical studies have consistently demonstrated significant improvement in rolling scars following subcision, either as a standalone procedure or as part of combination therapy [82,83].

Cannula-based subcision has gained popularity as a refinement of traditional techniques, offering improved safety and reduced risk of vascular injury. Blunt-tip cannulas allow for controlled dissection of fibrotic strands with less trauma to surrounding structures. This approach is particularly advantageous when treating larger surface areas or scars located in anatomically sensitive regions. Comparative studies suggest that cannula subcision achieves comparable efficacy to needle subcision with a lower incidence of bruising and patient discomfort [84,85].

Advanced subcision methods, including wire subcision and suction-assisted techniques, have been developed to enhance outcomes in severe or refractory cases. Wire subcision employs a flexible wire loop to transect dense fibrotic bands more effectively, while suction-assisted subcision aims to prevent re-adhesion of released scars by maintaining space during the early healing phase. Although promising, these techniques are more technically demanding and supported primarily by small clinical studies, highlighting the need for further validation [86,87].

Subcision is most effective when integrated into combination treatment protocols. Performing subcision prior to laser resurfacing, radiofrequency, or filler injection improves the efficacy of these modalities by eliminating mechanical constraints. Common adverse effects include transient bruising, swelling, and pain, while serious complications are rare when proper technique is employed. As an evidence-based, mechanism-targeted intervention, subcision remains an essential component of multimodal strategies for the treatment of atrophic acne scars [88,89].

Injectable Fillers for Acne Scars

Injectable fillers are used in atrophic acne scars to restore lost dermal volume and provide immediate elevation of depressed scars, particularly rolling and boxcar types. They are most effective after mechanical release of fibrotic tethering, such as with subcision, and are rarely recommended as monotherapy. Fillers act through direct volumization and, in some cases, by stimulating neocollagenesis, contributing to both short- and medium-term improvement in scar appearance [90,91].

Hyaluronic acid (HA) fillers are the most commonly used agents due to their favorable safety profile, reversibility, and ease of use. HA fillers provide immediate correction by lifting the scar base and

improving surface contour. Clinical studies have shown significant short-term improvement in acne scar depth and texture, particularly when HA fillers are injected into the deep dermis or subdermal plane following subcision. However, their effects are temporary, typically lasting 6–12 months, necessitating repeat treatments for maintenance [92,93].

Calcium hydroxylapatite (CaHA) fillers offer both volumizing and biostimulatory effects, promoting collagen production over time. Compared with HA, CaHA provides longer-lasting results and may be particularly useful for diffuse atrophic scarring. Nevertheless, CaHA is not reversible and requires greater technical expertise, especially in cosmetically sensitive areas, limiting its use to carefully selected patients [94,95].

Adverse effects of fillers include bruising, edema, nodule formation, and, rarely, vascular occlusion. When proper patient selection, anatomical knowledge, and injection techniques are employed, injectable fillers are a valuable adjunct in combination treatment protocols. Their role is best defined within multimodal strategies rather than as standalone therapy for atrophic acne scars [96,97].

Regenerative and Biologic Therapies

Regenerative and biologic therapies have gained increasing attention in the management of atrophic acne scars due to their potential to enhance wound healing and dermal regeneration. These approaches aim to augment intrinsic repair mechanisms by delivering growth factors, cytokines, or bioactive cells that stimulate fibroblast proliferation, angiogenesis, and collagen synthesis. Among these modalities, platelet-rich plasma (PRP) is the most extensively studied and widely used in clinical practice [98,99].

PRP is an autologous concentration of platelets suspended in plasma, rich in growth factors such as platelet-derived growth factor, transforming growth factor-β, and vascular endothelial growth factor. When applied intradermally or in combination with microneedling, lasers, or radiofrequency, PRP has been shown to accelerate healing, enhance collagen remodeling, and improve clinical outcomes compared with procedural treatments alone. Multiple randomized and split-face studies report superior scar improvement and reduced downtime when PRP is used as an adjunctive therapy [100,101].

Stem cell–based therapies, including adipose-derived stem cells and stromal vascular fraction, represent an emerging area of interest in acne scar treatment. These cells secrete bioactive mediators that promote tissue regeneration and extracellular matrix remodeling. Early clinical studies suggest potential benefit in improving scar texture and dermal thickness; however, evidence remains limited, and standardized protocols are lacking. Regulatory considerations and cost currently restrict their widespread clinical application [102,103].

Other regenerative approaches, such as topical or injectable growth factors and exosome-based therapies, are under investigation but remain largely experimental. While regenerative therapies appear safe and promising as adjuncts, high-quality comparative trials are needed to define their optimal role within multimodal treatment strategies. At present, their use should be considered complementary rather than standalone in the management of atrophic acne scars [104,105].

Conclusion

The management of atrophic acne scars has evolved substantially with the advent of advanced procedural and regenerative technologies. A deeper understanding of scar pathophysiology and morphology has shifted clinical practice away from single-modality interventions toward individualized, mechanism-based treatment strategies. Lasers, radiofrequency devices, microneedling, subcision, injectable fillers, and regenerative therapies each target distinct aspects of scar formation and contribute uniquely to clinical improvement.

No single treatment modality is universally effective for all atrophic acne scars. Instead, optimal outcomes are achieved through careful patient assessment, accurate scar classification, and rational combination of therapies. Subcision remains fundamental for tethered rolling scars, while energy-based devices and microneedling promote collagen remodeling and textural improvement. Injectable fillers and regenerative approaches provide valuable adjunctive benefits by restoring volume and enhancing wound healing responses.

Despite significant advances, challenges persist in standardizing treatment protocols, objectively

measuring outcomes, and minimizing adverse effects, particularly in patients with darker skin phototypes. Future progress will depend on high-quality comparative studies, long-term follow-up data, and the integration of emerging regenerative technologies. Ultimately, a personalized, multimodal, and evidence-based approach remains the cornerstone of effective atrophic acne scar management, with the goal of achieving meaningful, durable, and patient-centered outcomes.

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