Multidisciplinary Treatment Strategies for Acne Scars: Mechanisms and Emerging Therapeutic Approaches

Guanting Jin
Department of Exercise Science, The Ohio State University, Columbus, United Stated

Abstract: Acne scars are a common sequela of inflammatory acne and remain challenging to treat. They result from abnormal wound healing following dermal injury. Disruption of collagen remodeling and fibroblast regulation leads to structural alterations in the dermis and permanent irregularities on the skin surface. Previous studies have reported that acne scars can significantly affect patients' psychological well-being and quality of life. Various therapeutic approaches have been proposed, including drug therapy, microneedling, laser treatment, plasma devices, and autologous fat grafting. However, no single therapy is universally effective due to the complex biological mechanisms involved in scar formation. Energy-based treatments such as fractional CO_2 laser have been widely used to stimulate dermal remodeling and collagen regeneration. Microneedling therapy induces controlled micro-injury and activates fibroblast proliferation, which also contributes to collagen synthesis and skin regeneration. Recent advances in dermatologic technology emphasize multidisciplinary treatment strategies combining multiple therapeutic modalities. These combined approaches aim to target different pathological mechanisms involved in scar formation and improve overall clinical outcomes. This article reviews the biological mechanisms of acne scar formation and summarizes current treatment strategies including drug therapy, energy-based devices, plasma technology, and autologous fat grafting. A clinical case demonstrating multimodal treatment of acne scars is also presented.

Keywords: Acne Scars; Atrophic Scars; CO_2 Laser; Plasma Therapy; Autologous Fat Grafting; Dermatology

1. Introduction

Acne vulgaris is one of the most prevalent dermatological disorders worldwide. It primarily affects adolescents and young adults. A substantial proportion of patients develop permanent scarring following inflammatory acne lesions. Acne scars are mainly caused by abnormal wound healing after dermal injury. During inflammatory acne, destruction of collagen fibers and extracellular matrix occurs. When the repair process begins, collagen production may become dysregulated. This imbalance results in structural defects within the dermal layer [1]. Acne scarring can be broadly classified into atrophic scars caused by tissue loss and hypertrophic or keloid scars resulting from excessive tissue formation. The severity of scarring is often associated with the intensity and duration of inflammatory acne lesions [2].

Clinically, acne scars are classified into three primary types: ice-pick scars, boxcar scars, and rolling scars. Among these, atrophic scars represent the most common form and are characterized by depressed lesions on the skin surface [3].

Acne scarring not only causes cosmetic concerns but also significantly affects psychological health. Many patients experience reduced self-confidence and social anxiety due to visible facial scars. Various therapeutic approaches have been proposed to improve acne scars. These include chemical peeling, microneedling, laser therapy, radiofrequency devices, plasma technologies, dermal fillers, and autologous fat grafting.

Fractional CO_2 laser therapy is one of the most commonly used treatments. It creates microscopic zones of thermal injury that stimulate dermal remodeling and collagen synthesis [4]. Microneedling therapy has also demonstrated beneficial effects in treating atrophic scars by inducing controlled dermal injury and activating fibroblast activity [5].

Despite these advancements, acne scar management remains challenging because multiple pathological mechanisms are involved in scar formation. Therefore, recent studies

emphasize the importance of multidisciplinary treatment strategies that combine different therapeutic modalities.

This article reviews the mechanisms of acne scar formation and summarizes current treatment strategies. In addition, a clinical case of multimodal acne scar treatment is presented.

2. Skin Structure and Scar Formation

Understanding the structure of human skin is essential for interpreting the pathogenesis of scars. Human skin consists of three primary layers: the epidermis, dermis, and subcutaneous tissue. The epidermis forms the outer protective barrier of the skin. It contains keratinocytes and melanocytes and protects the body from environmental factors. The dermis lies beneath the epidermis and contains collagen fibers, elastic fibers, fibroblasts, and blood vessels. This layer provides mechanical strength and elasticity to the skin. It is also the primary location where scar formation occurs. The subcutaneous layer consists mainly of adipose tissue. It functions as a cushioning layer and energy reservoir. During inflammatory acne, damage extends into the dermal layer. Collagen fibers are destroyed and the structural integrity of the dermal matrix becomes disrupted. Fibroblasts are then activated to repair the tissue. However, the repair process may produce irregular collagen deposition. As a result, the regenerated tissue differs from normal skin structure. These alterations eventually lead to permanent acne scars.

3. Mechanisms of Persistent Scar Formation

Scar tissue differs significantly from normal skin in both biological function and structural organization. Several mechanisms contribute to the persistence of acne scars. First, collagen remodeling becomes dysregulated during wound healing. Fibroblasts produce excessive or disorganized collagen fibers, which form dense and irregular bundles. Second, fibroblast activity may remain abnormally elevated. Persistent fibroblast activation leads to excessive extracellular matrix production. Third, microvascular circulation in scar tissue is often impaired. Reduced blood supply limits oxygen delivery and delays tissue remodeling. Fourth, dermal regeneration is incomplete. Skin appendages such as hair follicles and sebaceous glands fail to regenerate during healing. Finally, pigmentation abnormalities may occur. Altered melanocyte activity can lead to post-inflammatory hyperpigmentation or hypopigmentation. These mechanisms explain why acne scars often persist for many years and remain difficult to treat.

4. Acne Scar Classification and Clinical Assessment

Accurate classification of acne scars is essential for selecting appropriate treatment strategies. Atrophic acne scars are typically categorized into three major morphological subtypes: ice-pick scars, boxcar scars, and rolling scars.

Ice-pick scars are narrow and deep lesions that extend vertically into the dermis. These scars often appear as small puncture-like depressions and are particularly difficult to treat because of their depth.

Boxcar scars are wider depressions with sharply defined edges. They may be shallow or deep depending on the extent of dermal damage.

Rolling scars are characterized by broad depressions with sloping edges. These scars are often associated with dermal tethering caused by fibrous bands beneath the skin surface.

In clinical practice, several grading systems have been proposed to assess acne scar severity. Among them, the Goodman and Baron qualitative grading system is widely used. This classification system categorizes scars into four grades based on their visibility and severity.

Grade 1 scars are macular and do not cause significant textural changes in the skin.

Grade 2 scars are mild and may be easily covered by makeup or facial hair.

Grade 3 scars represent moderate scarring that is visible at social distances but may flatten when the skin is stretched.

Grade 4 scars are severe and remain visible even when the skin is stretched [6].

In addition to the Goodman and Baron grading system, several other assessment tools have been developed, including the Investigator's Global Assessment (IGA) and the Echelle d'Evaluation Clinique des Cicatrices d'Acné (ECCA) [7]. This grading system provides a standardized approach for evaluating treatment outcomes and monitoring clinical improvement.

5. Principles of Scar Treatment

Modern acne scar treatment focuses on several key therapeutic objectives. These include reducing abnormal scar tissue, stimulating dermal regeneration, and promoting collagen

synthesis and remodeling. Effective treatment also aims to improve skin texture, restore surface smoothness, and correct pigmentation abnormalities associated with acne scarring.

In addition, remodeling of the extracellular matrix (ECM) has emerged as an important therapeutic target. The extracellular matrix plays a fundamental role in maintaining dermal structure and tissue integrity. Many contemporary treatment modalities aim to stimulate controlled dermal injury, which promotes collagen reorganization and restoration of normal dermal architecture [8].

Because acne scars involve multiple pathological processes, single-modality treatment is often insufficient. Therefore, combined treatment strategies are increasingly used in clinical practice to simultaneously target different aspects of scar pathology.

5.1 Drug Therapy

Drug therapy remains an important component of acne scar management. Common pharmacological treatments include corticosteroids, retinoids, and anti-inflammatory medications. These agents help reduce inflammation and regulate fibroblast activity. Topical silicone gel is also widely used in scar treatment. It maintains hydration of the stratum corneum and may improve scar appearance. Intralesional steroid injections are commonly used for hypertrophic scars and keloids. These injections suppress collagen synthesis and reduce scar thickness. Although drug therapy alone rarely eliminates acne scars, it can enhance the effectiveness of other treatment modalities.

5.2 Energy-Based Treatments

Energy-based devices are widely used in dermatologic therapy. Laser treatments are among the most effective technologies for acne scar management. Fractional CO_2 lasers create microscopic columns of thermal injury within the dermis. These microthermal zones trigger wound healing and collagen remodeling [4]. Pulsed dye lasers target vascular components of scars and reduce erythema. Radiofrequency devices deliver thermal energy into the dermis without damaging the epidermis. This process stimulates fibroblast activity and collagen production. Energy-based treatments promote dermal regeneration and improve skin texture.

5.3 Plasma Therapy

Plasma therapy represents a newer technology in dermatologic treatment. Plasma devices generate ionized gas that delivers controlled thermal energy to the skin surface. The energy penetrates into the dermis and stimulates tissue remodeling. This process promotes fibroblast activation and collagen synthesis. Consequently, skin texture gradually improves. Plasma therapy has advantages such as minimal invasiveness and relatively short recovery time. It has therefore become increasingly popular in aesthetic dermatology.

5.4 Autologous Fat Grafting

Autologous fat grafting has emerged as a promising treatment for depressed scars. The procedure involves several steps. First, adipose tissue is harvested from donor areas using liposuction. Second, the harvested fat is purified and processed. Third, fibrotic scar tissue is released through subcision. Finally, purified fat is injected into the dermal or subdermal layer. Adipose tissue contains adipose-derived stem cells that promote tissue regeneration and improve dermal quality. Fat grafting can restore lost volume and improve skin contour in patients with deep atrophic scars.

6. Clinical Case

A female patient with a history of persistent acne and atrophic acne scars was followed for approximately four years (2021–2025). The patient presented with moderate atrophic acne scars primarily located on the bilateral cheeks. Clinical examination revealed rolling scars and uneven skin texture.

Acne scar severity was evaluated using the Goodman and Baron qualitative grading system, and the patient was classified as Grade 3 (moderate acne scars) prior to treatment.

Clinical assessment of skin condition was also performed using the VISIA Complexion Analysis System, which provides objective evaluation of skin texture, pore structure, and pigmentation.

Between 2021 and 2025, the patient underwent multiple dermatologic treatments aimed at improving acne activity and scar appearance. These included five sessions of microneedling therapy, four sessions of laser-based skin repair treatment, and several chemical peeling procedures.

On July 15, 2024, the patient underwent the first fractional CO_2 laser treatment at Dalian

Dermatology Hospital. Subsequently, on August 15, 2024, radiofrequency microneedling (gold microneedle fractional therapy) was performed at Sha Doctor Medical Cosmetic Hospital in Dalian.

On May 6, 2025, the patient received combined laser therapy at a dermatology clinic in South Korea. Later, on June 30, 2025, autologous fat grafting was performed at Scar Research Hospital in Shenyang to improve depressed acne scars.

Finally, on November 25, 2025, the patient underwent plasma ion beam therapy at the same Shenyang institution.

Standardized clinical photographs were obtained before and after treatment under identical lighting conditions and patient positioning to allow objective comparison of treatment outcomes.

7. Results

Figure 1. Clinical Improvement of Atrophic Acne Scars after Autologous Fat Grafting

Standardized clinical photographs of a patient with atrophic acne scars.

Pre-treatment (6/30/2025, left) image showing depressed scars and uneven skin texture. Post-treatment (11/25/2025, right) image obtained after autologous fat grafting. A noticeable reduction in facial sebum production and inflammatory lesions was observed. The overall skin condition became more stable, and the depth of atrophic acne scars appeared reduced. The procedure involved harvesting adipose tissue, purification of the fat graft, subcision of fibrotic scar tissue, and reinjection of processed fat into the subdermal layer. Autologous fat grafting provides volume restoration and promotes dermal regeneration through adipose-derived stem cells.

Clinical photographs taken at two different time points prior to plasma therapy. Left Image obtained in 2024 before any scar-directed treatment. Right Image obtained in November 2025 prior to plasma ion beam therapy. The images demonstrate persistent atrophic acne scars with inflammatory lesions and post-inflammatory erythema. These findings highlight the chronic nature of acne scarring and the need for effective therapeutic intervention.

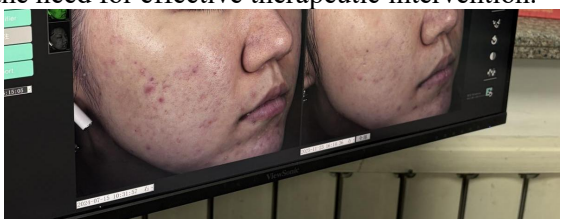

Figure 2. Progression of Acne Scars before Energy-Based Treatment

Visible clinical improvement was observed after treatment. Acne scar severity was assessed using the Goodman and Baron qualitative grading system. Before treatment, the patient presented with Grade 3 acne scars, characterized by visible rolling scars and uneven skin texture on both cheeks. Following treatment, the scar severity improved to Grade 2, with reduced scar depth and smoother skin appearance.

Clinical photographs demonstrated a visible improvement in skin contour and overall facial texture.

The number of inflammatory acne lesions was reduced compared with baseline photographs. Skin texture appeared smoother and more uniform. The depth of atrophic acne scars decreased, particularly in rolling scars and shallow boxcar scars. Post-inflammatory erythema was also reduced. In addition, autologous fat improved facial contour in depressed scar areas. Overall, the treatment resulted in noticeable cosmetic improvement. No obvious recurrence of inflammatory acne lesions was observed during follow-up.

8. Discussion

Acne scars often have a significant psychosocial impact on affected individuals. Previous studies have reported that patients with visible facial scarring frequently experience decreased self-confidence, social anxiety, and reduced quality of life. Although the primary objective of acne scar treatment is to improve skin texture and reduce scar depth, the psychological benefits of treatment should not be underestimated. Improvements in skin appearance may contribute to enhanced self-esteem and overall well-being. In the present case, noticeable

improvement in facial texture and scar depth was observed following multimodal treatment. These changes may have important implications for patient satisfaction and psychological outcomes. Therefore, future studies evaluating acne scar treatments should consider incorporating patient-reported outcome measures, such as quality-of-life assessments, to better understand the broader impact of therapeutic interventions.

The pathogenesis of acne scars involves multiple biological processes including collagen destruction, abnormal fibroblast activity, and impaired dermal regeneration. Therefore, a single therapeutic modality is often insufficient to achieve optimal clinical outcomes. Multimodal treatment strategies aim to target different pathological mechanisms simultaneously. Energy-based devices such as fractional CO_2 laser primarily induce controlled thermal injury within the dermis. These microthermal zones stimulate wound healing responses and promote collagen remodeling. Microneedling therapy produces mechanical micro-injuries that activate fibroblasts and enhance the synthesis of new collagen and elastin fibers. Recent studies have shown that autologous adipose tissue not only provides volume filling but also contains abundant adipose-derived stem cells (ADSCs). These cells can secrete various cytokines and growth factors, promoting angiogenesis and tissue regeneration, thereby improving the structure of scar tissue. Therefore, autologous fat filling not only has a mechanical filling effect but also has certain regenerative medical significance [9]. Plasma technology delivers ionized energy that stimulates dermal regeneration and improves skin texture. By combining these approaches, multidisciplinary treatment strategies address multiple aspects of scar pathology, including collagen remodeling, dermal regeneration, and structural volume restoration [10].

In recent years, advances in regenerative medicine have opened new possibilities for acne scar treatment. Emerging therapies such as stem cell–based approaches, platelet-rich plasma (PRP), and biomaterial scaffolds are being explored for their potential to enhance dermal regeneration. Platelet-rich plasma contains a high concentration of growth factors such as platelet-derived growth factor (PDGF) and transforming growth factor (TGF-β), which can promote tissue repair and collagen production. Studies have shown that the combination of PRP and microneedle therapy can significantly improve the improvement rate of acne scars and patient satisfaction. Therefore, PRP may become an important auxiliary method in future multimodal treatment strategies [11].

In addition, tissue engineering technologies and bioactive materials are being investigated as potential methods to restore damaged dermal structures. Although these approaches remain under investigation, they represent promising future directions for improving acne scar treatment.

Limitations and Future Perspectives:

Although the present study demonstrates visible clinical improvement following multidisciplinary treatment, several limitations should be considered. First, this study is based on a single clinical case. Therefore, the results may not be generalizable to a larger population. Second, quantitative measurement of scar improvement was limited. Future studies may incorporate objective evaluation tools such as three-dimensional imaging systems or digital skin analysis. Third, long-term follow-up is necessary to determine the durability of treatment outcomes and to evaluate potential recurrence of acne lesions or scars. Future research should focus on larger clinical studies to evaluate the efficacy of multimodal treatment strategies for acne scars. In addition, advances in regenerative medicine, stem cell therapy, and biomaterials may provide new therapeutic approaches for scar management.

9. Conclusion

Acne scars are caused by complex biological processes involving collagen remodeling, fibroblast activity, and dermal regeneration. Modern dermatologic treatments include drug therapy, energy-based devices, plasma technologies, and autologous fat grafting. Multidisciplinary treatment strategies that combine different modalities may offer improved clinical outcomes. Further studies with larger patient populations are needed to confirm the effectiveness of these treatment approaches.

References

[1] Meghe, Soham R et al. “Shedding Light on Acne Scars: A Comprehensive Review of CO2 vs. Erbium-Doped Yttrium Aluminium Garnet (Er:YAG) Laser Therapy.” Cureus vol. 16, 4 e57572. 3 Apr. 2024, doi: 10.7759/cureus.57572

[2] Qoreishi, Seyedeh Hoda et al. “Advancements in Acne Scar Treatment: Exploring Novel Therapies.” Journal of cosmetic dermatology vol. 24, 5 (2025): e70183. doi:10.1111/jocd.70183.

[3] Ahramiyanpour, Najmeh et al. “Optimizing Post-Acne Scar Treatment: A Pilot Comparative Study of Endo-Radiofrequency Subcision with and Without Platelet-Rich Plasma.” Journal of cosmetic dermatology vol. 24, 7 (2025): e70345. doi: 10.1111/jocd.70345.

[4] Petrov, Andrej, and Vesna Pljakovska. “Fractional Carbon Dioxide Laser in Treatment of Acne Scars.” Open access Macedonian journal of medical sciences vol. 4, 1 (2016): 38-42. doi: 10.3889/oamjms. 2016.004.

[5] Minh, Phuong Pham Thi et al. “Microneedling Therapy for Atrophic Acne Scar: Effectiveness and Safety in Vietnamese Patients.” Open access Macedonian journal of medical sciences vol. 7, 2 293-297. 29 Jan. 2019, doi:10.3889/oamjms.2019.098.

[6] Goodman, G. J., & Baron, J. A. (2006). Postacne scarring: a qualitative global scarring grading system. Dermatologic surgery: official publication for American Society for Dermatologic Surgery [et al.], 32(12), 1458–1466. https://doi.org/10. 1111/j.1524-4725.2006. 32354.x.

[7] Bae, In Ho et al. “A Comprehensive Review of the Acne Grading Scale in 2023.” Annals of dermatology vol. 36, 2 (2024): 65-73. doi:10.5021/ad.23.094.

[8] Fabbrocini, Gabriella et al. “Acne scars: pathogenesis, classification and treatment.” Dermatology research and practice vol. 2010 (2010): 893080. doi: 10.1155/2010/893080.

[9] Stachura, Albert et al. “The Use of Adipose-Derived Stem Cells (ADSCs) and Stromal Vascular Fraction (SVF) in Skin Scar Treatment-A Systematic Review of Clinical Studies.” Journal of clinical medicine vol. 10, 16 3637. 17 Aug. 2021, doi: 10.3390/jcm10163637.

[10] Tahiliani, Sushil et al. “Practical Aspects of Acne Scar Management: ASAP 2024.” Cureus vol. 16, 3 e55897. 10 Mar. 2024, doi:10.7759/cureus.55897.

[11] Kang C and Lu D (2022) Combined Effect of Microneedling and Platelet-Rich Plasma for the Treatment of Acne Scars: A Meta-Analysis. Front. Med. 8:788754. doi: 10.3389/fmed.2021.788754.

