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INTEGRATED SCAR MANAGEMENT: CURRENT EVIDENCE ON CONSERVATIVE, REGENERATIVE, AND LASER-BASED THERAPIES - A NARRATIVE REVIEW

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ABSTRACT

Pathological scarring remains a major challenge in reconstructive, plastic, and aesthetic medicine owing to the complex biology of wound healing, marked heterogeneity of scar phenotypes, and the lack of universally effective treatment strategies. Advances in regenerative medicine and laser technologies have expanded therapeutic options while increasing the need for individualized, evidence-based treatment.

This narrative review synthesizes current evidence on conservative, regenerative, and laser-based therapies for scar management, emphasizing their biological rationale, clinical effectiveness, limitations, and role within contemporary multimodal treatment strategies. The literature was identified through searches of PubMed, Scopus, and Web of Science, with priority given to systematic reviews, meta-analyses, randomized controlled trials, international guidelines, and other high-quality evidence.

Current evidence indicates that successful scar management depends on matching treatment to scar phenotype and biological activity rather than relying on a single therapeutic modality. Conservative therapies remain the foundation of treatment, whereas regenerative approaches and laser technologies enhance outcomes, particularly when integrated into multimodal protocols. Despite substantial therapeutic progress, heterogeneity of available evidence continues to limit direct comparison and standardization of treatment strategies.

Overall, contemporary scar management is evolving toward personalized, mechanism-based approaches that integrate complementary therapies to optimize functional and aesthetic outcomes.

KEYWORDS

Scar Management; Pathological Scars; Wound Healing; Regenerative Medicine; Laser Therapy; Multimodal Therapy

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1. Introduction

Pathological scars remain a major challenge in reconstructive, plastic, and aesthetic medicine because they may impair physical function, cause pain, pruritus, psychological distress, and significantly reduce quality of life. Despite considerable advances in wound healing research and the growing number of available therapeutic options, no universally effective treatment has been established, reflecting the biological heterogeneity of pathological scarring and the complexity of tissue repair [1-6].

Current understanding recognizes pathological scars as the consequence of dysregulated wound healing involving persistent inflammation, fibroblast activation, extracellular matrix (ECM) remodeling, mechanotransduction, angiogenesis, and immune dysregulation [1-6]. These interconnected biological processes vary among scar phenotypes and throughout scar maturation, explaining the marked variability in clinical presentation and therapeutic response. Consequently, contemporary scar management has evolved from procedure-based treatment toward biologically informed, evidence-based, and personalized therapeutic strategies [7-9].

At the same time, therapeutic possibilities have expanded substantially, encompassing conservative therapy, intralesional pharmacotherapy, regenerative medicine, surgical revision, and advanced laser technologies. However, the available evidence remains heterogeneous, and most published reviews evaluate individual therapeutic modalities rather than their integration within comprehensive multimodal treatment strategies [6-9].

Therefore, this narrative review critically summarizes current evidence regarding conservative, regenerative, surgical, and laser-based therapies for pathological scar management. Particular emphasis is placed on the biological rationale underlying these interventions, their clinical effectiveness, and the role of multimodal treatment strategies in optimizing both functional and aesthetic outcomes.

2. Materials and Methods

This narrative review was based on a literature search conducted in PubMed, Scopus, and Web of Science. Priority was given to systematic reviews, meta-analyses, randomized controlled trials, international guidelines, and high-quality observational studies. Landmark publications were included where necessary to provide historical and biological context. The retrieved literature was critically synthesized with emphasis on scar biology, therapeutic mechanisms, clinical effectiveness, and multimodal treatment strategies.

2.1.1 Normal Wound Healing

Physiological wound healing provides the biological foundation for contemporary scar management, as pathological scars arise from dysregulation of normal tissue repair rather than from distinct pathological processes. Wound healing is a dynamic and tightly coordinated process comprising hemostasis, inflammation, proliferation, and remodeling, regulated through complex interactions among inflammatory cells, fibroblasts, endothelial cells, keratinocytes, growth factors, cytokines, and the extracellular matrix (ECM). [1,2]

Under physiological conditions, these overlapping phases restore tissue integrity and progressively reorganize the extracellular matrix. In contrast, persistent inflammation, dysregulated fibroblast activity, abnormal collagen remodeling, and altered mechanobiological signaling may lead to excessive fibrosis and pathological scar formation. [1-6]

Consequently, contemporary scar therapies increasingly focus on modulating the biological mechanisms of wound healing rather than simply correcting established scars, providing the foundation for biologically informed and multimodal therapeutic strategies. [7-9]

2.1.2 Biological Networks Driving Pathological Scar Formation

Current evidence indicates that pathological scar formation results from dysregulation of coordinated biological processes rather than excessive collagen deposition alone. Failure to restore tissue homeostasis following injury leads to persistent activation of inflammatory, fibrotic, vascular, and mechanobiological pathways that collectively sustain pathological tissue remodeling. [2,5-7]

Persistent inflammation promotes prolonged fibroblast activation, excessive extracellular matrix (ECM) deposition, abnormal collagen remodeling, and dysregulated mechanobiological signaling. These interconnected processes reinforce one another through self-perpetuating profibrotic feedback loops, contributing to the biological heterogeneity of pathological scars and the variability in clinical presentation and treatment response. [5-7]

This systems-based understanding of scar biology provides the biological rationale for contemporary scar management. Rather than targeting isolated molecular pathways, current therapeutic strategies increasingly integrate conservative, regenerative, surgical, and laser-based interventions to modulate complementary mechanisms involved in tissue repair and scar remodeling. [7-9]

2.1.3 Scar Phenotypes as Distinct Biological Entities

Current evidence indicates that pathological scars represent biologically distinct entities rather than variations of a single disease process. Although traditionally classified according to their clinical appearance, hypertrophic scars, keloids, atrophic scars, and post-burn scars differ substantially in their underlying mechanisms of inflammation, fibrosis, extracellular matrix (ECM) remodeling, mechanobiology, and regenerative capacity. [4-7]

Hypertrophic scars are characterized by excessive but self-limiting fibrosis confined to the original wound, whereas keloids exhibit persistent fibroproliferation extending beyond wound margins. In contrast, atrophic scars result from impaired dermal regeneration and reduced collagen deposition, while post-burn scars represent the most heterogeneous phenotype, frequently combining fibrosis, contracture, pigmentary abnormalities, and functional impairment. [3-7]

Recognition of these biological differences has fundamentally changed therapeutic decision-making. Contemporary scar management increasingly emphasizes phenotype-oriented treatment, in which therapeutic strategies are selected according to the dominant biological mechanisms underlying individual scars rather than their clinical appearance alone. [7-9]

2.2.1 Principles of Conservative Therapy

Conservative therapy remains the cornerstone of scar prevention and early management because it modulates the biological processes driving pathological scar formation before irreversible fibrosis becomes established. Its principal objectives are to reduce inflammation, regulate fibroblast activity, maintain extracellular matrix (ECM) homeostasis, and minimize mechanical forces that contribute to pathological scar remodeling. [7-10]

Current international guidelines recommend silicone-based products and intralesional corticosteroids as first-line treatments for hypertrophic scars and keloids, whereas pressure therapy, cryotherapy, and other conservative interventions are selected according to scar phenotype, stage of maturation, anatomical location, and clinical presentation. [8-13]

Increasing evidence supports early, individualized intervention and integration of conservative therapy with regenerative, surgical, and laser-based procedures to optimize long-term functional and aesthetic outcomes. This multimodal approach reflects the growing recognition that successful scar management requires modulation of multiple biological pathways rather than reliance on a single therapeutic modality. [7-9,13]

2.2.2 Silicone-Based Therapy

Silicone gel and silicone gel sheeting remain the cornerstone of conservative scar prevention and early management and are consistently recommended as first-line therapy for hypertrophic scars by international guidelines. Their therapeutic effects are primarily attributed to restoration of epidermal hydration, reduction of transepidermal water loss, and modulation of the local wound environment, thereby reducing fibroblast activity and promoting physiological scar maturation. [8-11]

Systematic reviews and meta-analyses consistently demonstrate improvements in scar thickness, erythema, pliability, pruritus, and overall scar quality, particularly when treatment is initiated during the early phases of scar maturation. However, interpretation of these findings is limited by heterogeneity in study design, treatment protocols, patient populations, and outcome measures. Clinical benefit is greatest in immature hypertrophic and postoperative scars, whereas evidence supporting treatment of mature scars remains less consistent. [10-12]

Although silicone therapy does not reverse established fibrosis, it remains the foundation of conservative scar management by optimizing the biological environment for scar maturation and facilitating integration with subsequent multimodal treatment when indicated. [7-10]

2.2.3 Intralesional Pharmacotherapy

Intralesional pharmacotherapy remains the standard minimally invasive treatment for hypertrophic scars and keloids when topical therapy alone is insufficient. Corticosteroids continue to be the first-line agents because they suppress fibroblast proliferation, collagen synthesis, and inflammatory activity, resulting in improvements in scar thickness, erythema, pruritus, and overall scar symptoms. However, recurrence following corticosteroid monotherapy remains common, particularly in keloids, and repeated injections may be associated with skin atrophy, telangiectasia, and pigmentary changes. [8,12-14]

To improve therapeutic efficacy, corticosteroids are increasingly combined with other intralesional agents. Among these, 5-fluorouracil (5-FU) has the strongest supporting evidence, demonstrating greater scar flattening, lower recurrence rates, and fewer corticosteroid-related adverse effects than steroid monotherapy.

Bleomycin may provide additional benefit in selected treatment-resistant scars, whereas evidence supporting botulinum toxin type A remains encouraging but limited. [12-14]

Current evidence supports intralesional pharmacotherapy as an integral component of multimodal scar management rather than a standalone intervention. Combination with surgery, silicone therapy, cryotherapy, or laser-based procedures generally provides superior long-term outcomes compared with monotherapy, particularly in recurrent hypertrophic scars and keloids. [7-9,12-14]

2.2.4 Pressure and Compression Therapy

Pressure therapy remains an established component of conservative scar management, particularly for the prevention and treatment of hypertrophic burn scars. Its biological effects are attributed to reduction of tissue edema, modulation of fibroblast activity, collagen remodeling, and attenuation of mechanical forces that contribute to pathological scar maturation. [9-11]

Current international guidelines recommend pressure garments primarily for patients with extensive burn scars and prolonged wound healing. Although clinical studies have demonstrated improvements in scar thickness, pliability, and scar-related symptoms, the overall certainty of evidence remains limited because of heterogeneity in treatment protocols, applied pressure, treatment duration, patient populations, and outcome measures. [9-11]

Long-term adherence represents the principal limitation of pressure therapy, as clinically meaningful benefit generally requires prolonged daily garment use over several months. Consequently, pressure therapy should be regarded as one component of individualized multimodal scar management, particularly within comprehensive burn rehabilitation programs, rather than as a universally applicable intervention. [7-10]

2.2.5 Cryotherapy

Cryotherapy remains an established treatment for hypertrophic scars and selected keloids, although its current role is primarily as an adjunctive rather than first-line therapy. Repeated freeze–thaw cycles induce fibroblast destruction, vascular injury, and reduced collagen synthesis, thereby limiting fibroproliferative activity and promoting physiological scar remodeling. [9,12,13]

Clinical studies have demonstrated improvements in scar thickness, elevation, pruritus, and overall scar symptoms, particularly in small hypertrophic scars and selected keloids. However, the certainty of evidence remains limited because of heterogeneous treatment protocols, relatively small study populations, variable outcome measures, and limited long-term follow-up. Current evidence indicates that cryotherapy is most effective when combined with intralesional corticosteroids, 5-fluorouracil, surgery, or laser-based procedures rather than when used as monotherapy. [12,13]

Pain, blistering, delayed wound healing, and pigmentary alterations, particularly hypopigmentation in patients with darker skin phototypes, remain the principal limitations of treatment. Consequently, cryotherapy should be reserved for carefully selected patients as part of an individualized multimodal treatment strategy. [7-9,12]

2.2.6 Surgical Scar Revision

Surgical scar revision is indicated for selected pathological scars associated with functional impairment, contracture, pain, or significant cosmetic deformity. Its primary objective is to restore tissue architecture, reduce mechanical tension, and create favorable conditions for physiological wound healing and scar remodeling. [7,9,35]

Clinical outcomes depend largely on scar phenotype, surgical technique, and postoperative management. Surgical revision may provide durable improvement in hypertrophic scars, whereas excision alone is associated with high recurrence rates in keloids and is therefore not recommended as definitive treatment. Current international guidelines support combining surgery with adjuvant therapies, including silicone-based products, intralesional corticosteroids, laser-based procedures, or postoperative radiotherapy in selected high-risk patients to reduce recurrence. [9,14,35]

Because every surgical procedure initiates a new wound-healing response, careful patient selection, meticulous surgical technique, and structured postoperative scar management remain essential for achieving favorable long-term outcomes. Consequently, surgical scar revision should be regarded as one component of an individualized multimodal treatment strategy rather than a standalone intervention. [1,7-9]

2.3.1 Principles of Regenerative Scar Therapy

Regenerative therapies aim to restore physiological tissue repair by promoting tissue regeneration rather than simply suppressing fibrosis. Unlike conventional conservative treatments, they stimulate endogenous healing processes through collagen remodeling, angiogenesis, extracellular matrix (ECM) regeneration, and intercellular signaling, thereby supporting restoration of tissue homeostasis. [15,16]

Current regenerative approaches, including platelet-rich plasma (PRP), microneedling, radiofrequency, stem cell-derived products, and extracellular vesicles, have demonstrated the greatest clinical benefit in scars characterized by impaired tissue regeneration, particularly atrophic scars. However, considerable heterogeneity in biological preparations, treatment protocols, treatment schedules, and outcome measures continues to limit direct comparison among available regenerative techniques. [15-18]

Regenerative therapies are increasingly integrated with conservative, surgical, and laser-based interventions within individualized multimodal treatment strategies. This approach reflects the growing recognition that effective scar remodeling requires coordinated modulation of complementary biological pathways rather than isolated therapeutic interventions. [7,15-18]

2.3.2 Platelet-Rich Plasma (PRP)

Platelet-rich plasma (PRP) is the most extensively investigated regenerative therapy in scar management and remains the reference biologic treatment against which many emerging regenerative approaches are compared. By delivering a concentrated source of autologous growth factors, PRP promotes angiogenesis, collagen synthesis, extracellular matrix (ECM) remodeling, and tissue regeneration. [15,18,19]

Current evidence indicates that PRP is most effective when combined with procedures such as fractional laser therapy or microneedling rather than when used as monotherapy. Systematic reviews and meta-analyses consistently demonstrate improvements in scar texture, appearance, and patient satisfaction, particularly in atrophic acne scars. In contrast, evidence supporting its use in hypertrophic scars and keloids remains limited and primarily supports PRP as an adjunctive therapy integrated with other treatment modalities. [15,18-20]

Interpretation of the available literature is limited by substantial variability in PRP preparation methods, platelet concentration, treatment protocols, and outcome measures. Nevertheless, PRP remains the best-established regenerative therapy and is increasingly incorporated into multimodal treatment strategies to enhance tissue repair and optimize scar remodeling. [7,15,18-20]

2.3.3 Microneedling

Microneedling is a minimally invasive regenerative procedure that promotes physiological wound healing through controlled dermal microinjury while preserving epidermal integrity. This process stimulates collagen neosynthesis, extracellular matrix (ECM) remodeling, angiogenesis, and tissue regeneration, resulting in effective scar remodeling with minimal downtime and a low risk of pigmentary complications. [16,20]

Current evidence supports microneedling as an effective treatment for atrophic acne scars. Systematic reviews and meta-analyses have demonstrated significant improvements in scar severity, skin texture, and patient satisfaction, whereas combination with platelet-rich plasma or other regenerative therapies further enhances clinical outcomes. However, evidence supporting its use in hypertrophic scars and keloids remains limited, and treatment protocols have not yet been fully standardized. [16,18-20]

Because of its favorable safety profile, broad applicability, and compatibility with multimodal treatment strategies, microneedling has become one of the best-established regenerative procedures for atrophic scar management. Its ability to enhance tissue regeneration while facilitating combination therapy further supports its role within contemporary personalized scar treatment algorithms. [7,16,18,20]

2.3.4 Radiofrequency

Radiofrequency (RF), particularly fractional microneedle radiofrequency (FMR), is an established regenerative treatment for atrophic scars. By delivering controlled thermal energy to the dermis, RF promotes collagen remodeling, neocollagenesis, extracellular matrix (ECM) reorganization, and tissue regeneration while preserving epidermal integrity and minimizing recovery time. [21,22]

Systematic reviews and randomized controlled trials have demonstrated significant improvements in scar depth, skin texture, and patient satisfaction, with clinical outcomes comparable to fractional laser therapy in appropriately selected patients. RF may be particularly advantageous in individuals with darker skin phototypes because of its lower risk of post-inflammatory hyperpigmentation. However, heterogeneity in RF devices, treatment parameters, treatment protocols, and outcome measures continues to limit direct comparison among clinical studies. [21,22]

Current evidence supports RF as an effective regenerative option for atrophic scars, whereas its role in hypertrophic scars and keloids remains insufficiently established. Increasingly, RF is incorporated into multimodal treatment strategies in combination with platelet-rich plasma, microneedling, or laser-based procedures to enhance tissue regeneration and optimize scar remodeling. [7,18,21,22]

2.3.5 Stem Cell-Derived Therapies and Extracellular Vesicles

Stem cell-derived therapies and extracellular vesicles (EVs), particularly exosomes, represent promising emerging approaches in regenerative scar management. Current evidence indicates that the therapeutic effects of mesenchymal stem cells (MSCs) are mediated predominantly through paracrine signaling rather than direct cellular engraftment, driving the development of cell-free regenerative strategies. [23-25]

Preclinical studies have demonstrated that MSC-derived EVs modulate inflammation, fibroblast activity, extracellular matrix (ECM) remodeling, angiogenesis, collagen organization, and intercellular signaling, thereby promoting more physiological wound healing and tissue regeneration. Early clinical studies also suggest improvements in scar quality, skin regeneration, and cosmetic outcomes; however, most available evidence remains derived from small clinical studies and experimental models. Variability in cell sources, EV isolation methods, manufacturing protocols, dosing strategies, and treatment protocols continues to limit standardization and clinical translation. [23-25]

At present, stem cell-derived therapies and EVs should be regarded as investigational. Well-designed randomized controlled trials, standardized manufacturing procedures, long-term safety evaluation, and regulatory harmonization are required before routine clinical implementation can be recommended. [24,25]

2.3.6 Laser-Assisted Drug Delivery (LADD)

Laser-assisted drug delivery (LADD) is an emerging therapeutic platform that enhances transdermal delivery of pharmacological and regenerative agents through microscopic treatment channels created by fractional laser technologies. This approach substantially improves the penetration of compounds with otherwise limited skin permeability, including corticosteroids, 5-fluorouracil, platelet-rich plasma, growth factors, and experimental regenerative biologics, thereby expanding the therapeutic potential of laser-based scar management and multimodal treatment strategies. [24,26,31,32]

Early clinical studies suggest that LADD may improve outcomes in hypertrophic scars and keloids, particularly when combined with topical or intralesional therapies. Nevertheless, the available evidence remains limited by heterogeneous laser parameters, treatment protocols, drug delivery techniques, relatively short follow-up periods, and the lack of standardized treatment algorithms. Consequently, further comparative clinical studies are required to define the optimal indications and procedural parameters for routine clinical practice. [24,31,32]

At present, LADD should be regarded as a promising adjunctive technology within individualized multimodal scar management rather than a standalone therapeutic modality. Its greatest potential lies in facilitating biologically targeted combination therapies that integrate laser treatment with regenerative and pharmacological interventions. However, well-designed randomized controlled trials are still required to establish standardized treatment protocols, identify the most effective therapeutic agents, and determine long-term clinical effectiveness before routine implementation can be recommended. [7,26,31,32]

2.4.1 Principles of Laser-Based Scar Remodeling

Laser therapy has become one of the most effective procedural approaches in contemporary scar management by enabling precise biological modulation of tissue remodeling through controlled photothermal injury. Depending on the laser type and treatment parameters, laser-induced tissue remodeling promotes collagen remodeling, neocollagenesis, vascular modification, extracellular matrix (ECM) reorganization, and restoration of tissue architecture. [28-30]

The introduction of fractional photothermolysis has fundamentally improved the safety and effectiveness of laser therapy by creating microscopic treatment zones surrounded by intact tissue, thereby accelerating healing while preserving therapeutic efficacy. Current evidence demonstrates significant improvements in scar thickness, texture, pigmentation, erythema, pliability, and overall scar quality, although optimal treatment selection should be guided by scar phenotype, biological activity, stage of maturation, and individual patient characteristics. [28-31]

Rather than representing an isolated therapeutic modality, laser technologies have become integral components of multimodal scar management. Increasing evidence supports their combination with regenerative therapies, intralesional pharmacotherapy, and laser-assisted drug delivery, reflecting the transition toward biologically guided, personalized treatment strategies. [7,28-32]

2.4.2 Ablative Fractional Lasers

Ablative fractional lasers, particularly carbon dioxide (CO_2) and erbium-doped yttrium aluminum garnet (Er:YAG) systems, remain the reference standard for procedural scar remodeling because they induce controlled dermal regeneration through fractional photothermolysis. Compared with non-ablative laser systems, they achieve deeper tissue remodeling, more extensive collagen reorganization, and greater structural scar remodeling, making them particularly effective for hypertrophic, postoperative, burn, and severe atrophic scars. [28-30]

Multiple randomized controlled trials, systematic reviews, and meta-analyses have consistently demonstrated significant improvements in scar thickness, texture, pliability, contracture, and patient-reported outcomes. Fractional CO_2 lasers generally achieve more extensive remodeling because of their greater thermal effect, whereas Er:YAG lasers provide faster healing with less residual thermal injury and shorter recovery time. Despite their effectiveness, ablative fractional lasers are associated with longer downtime and a higher risk of erythema, post-inflammatory hyperpigmentation, and other treatment-related adverse effects, requiring careful patient selection and individualized treatment parameters. [29-31]

Current evidence supports ablative fractional lasers as a cornerstone of multimodal scar management. Their combination with regenerative therapies, intralesional pharmacotherapy, and laser-assisted drug delivery has further expanded their therapeutic potential by enhancing tissue regeneration while optimizing long-term scar remodeling. [7,18,29-32]

2.4.3 Non-Ablative Fractional Lasers

Non-ablative fractional lasers promote dermal remodeling while preserving epidermal integrity, providing effective scar treatment with shorter recovery time and a lower risk of treatment-related adverse effects than ablative laser systems. Fractional erbium glass lasers (1540–1565 nm) are the best-studied devices and have demonstrated particular effectiveness in atrophic acne scars, immature postoperative scars, and selected hypertrophic scars through stimulation of collagen remodeling and extracellular matrix (ECM) regeneration. [29-31]

Systematic reviews, meta-analyses, and randomized controlled trials have consistently demonstrated significant improvements in scar texture, pliability, pigmentation, and patient satisfaction. However, clinical improvement is generally more gradual than with ablative fractional lasers and typically requires multiple treatment sessions. Their favorable safety profile makes non-ablative lasers particularly suitable for individuals with darker skin phototypes, anatomically sensitive areas, and patients seeking minimal downtime. [29-31]

Current evidence supports non-ablative fractional lasers as an effective alternative or complement to ablative laser therapy. Increasingly, they are incorporated into multimodal treatment protocols in combination with regenerative therapies, laser-assisted drug delivery, and other procedural interventions to optimize tissue regeneration and scar remodeling. Treatment selection should therefore be individualized according to scar phenotype, biological activity, stage of maturation, and patient-specific therapeutic goals. [7,29-32]

2.4.4 Vascular Lasers

Vascular lasers selectively target abnormal scar microvasculature, making them particularly effective for erythematous and immature hypertrophic scars. Through selective photothermolysis of oxyhemoglobin, they reduce pathological vascularity, attenuate inflammatory activity, and indirectly suppress fibroblast activation, thereby limiting pathological scar progression during the early phases of wound healing. [29-31]

The pulsed dye laser (PDL; 585–595 nm) remains the best-studied vascular laser and is considered the treatment of choice for erythematous hypertrophic scars. Randomized controlled trials, systematic reviews, and meta-analyses have consistently demonstrated significant improvements in erythema, pruritus, scar pliability, thickness, and patient-reported outcomes. Long-pulsed Nd:YAG (1064 nm) may provide additional benefit in thicker or more vascular scars because of its greater tissue penetration, although supporting evidence remains less extensive. [29-31]

Current evidence indicates that vascular lasers are most effective when initiated during the active phases of scar maturation and demonstrate limited efficacy in mature fibrotic scars. Their favorable safety profile and complementary role alongside fractional laser technologies support their incorporation into individualized multimodal treatment strategies, particularly when combined with regenerative therapies or other laser-based procedures. [7,29-31]

2.4.5 Combination Laser Therapy

Increasing evidence indicates that combination laser therapy provides superior clinical outcomes compared with single-modality treatment by simultaneously targeting complementary biological mechanisms involved in pathological scar remodeling. Fractional ablative and non-ablative lasers are frequently combined with vascular lasers to improve scar texture, thickness, pigmentation, erythema, pliability, and overall scar quality while addressing different stages of scar maturation. [29-32]

Additional clinical benefit has been demonstrated when laser therapy is integrated with regenerative and pharmacological interventions, including platelet-rich plasma, intralesional corticosteroids, silicone-based therapy, and laser-assisted drug delivery. These multimodal approaches enhance tissue regeneration, optimize extracellular matrix remodeling, and improve long-term clinical outcomes, particularly in complex hypertrophic, burn, and postoperative scars. [18,24,29-32]

Current evidence supports individualized combination protocols based on scar phenotype, biological activity, stage of maturation, anatomical location, and patient-specific therapeutic goals rather than routine application of a single laser modality. Although further standardization of treatment algorithms remains necessary, combination laser therapy increasingly represents the contemporary standard of biologically guided and multimodal scar management. [7,29-32]

2.4.6 Future Directions: Precision and Personalized Scar Management

Future advances in scar management are expected to focus on precision medicine rather than the development of individual therapeutic technologies. Emerging biomarkers, molecular profiling, advanced imaging, and artificial intelligence (AI) are expected to improve scar phenotyping, predict treatment response, and support personalized therapeutic decision-making. AI-assisted image analysis and predictive models may further enhance objective scar assessment, individualized treatment planning, and longitudinal monitoring. [27,30-32]

Further progress is likely to result from closer integration of regenerative medicine, laser technologies, targeted drug delivery, and multimodal therapeutic strategies tailored to the biological characteristics of individual scars. However, widespread clinical implementation will require standardized treatment protocols, robust biomarker validation, high-quality randomized clinical trials, and external validation of AI-based decision-support systems. [24,27,31,32]

Current evidence suggests that the future of scar management lies in personalized, biology-guided therapeutic strategies that integrate complementary technologies according to scar phenotype, stage of maturation, and patient-specific characteristics rather than relying on increasingly sophisticated technologies alone. [7,27,30-32]

3. Discussion

The present review demonstrates that contemporary scar management has evolved from a procedure-oriented approach toward biologically informed, evidence-based therapeutic strategies. Advances in the understanding of wound healing, mechanobiology, inflammation, extracellular matrix remodeling, and tissue regeneration have fundamentally changed the rationale underlying scar treatment. Rather than identifying a universally superior intervention, current evidence increasingly supports tailoring therapy according to scar phenotype, stage of maturation, anatomical location, and patient-specific characteristics. This paradigm shift reflects the growing recognition that pathological scars represent biologically heterogeneous entities requiring individualized management rather than standardized treatment algorithms. [6-9,35]

One of the most consistent findings across the available literature is the superiority of multimodal treatment over isolated therapeutic interventions. Conservative therapies remain the cornerstone of early scar prevention and management, whereas regenerative medicine, laser technologies, and surgical revision achieve the greatest clinical benefit when integrated into sequential, biologically complementary treatment protocols. Combining therapies that target inflammation, fibroblast activation, extracellular matrix remodeling, angiogenesis, mechanotransduction, and tissue regeneration appears to provide more durable structural, functional, and aesthetic improvement than single-modality treatment. Recent studies evaluating platelet-rich plasma, microneedling, radiofrequency, combination laser protocols, and laser-assisted drug delivery further support this integrated therapeutic concept across multiple scar phenotypes. [7-9,18-24,29-35]

Despite substantial therapeutic progress, important limitations of the current evidence should be acknowledged. Although numerous systematic reviews and meta-analyses have been published, many include heterogeneous scar classifications, treatment protocols, laser parameters, regenerative preparations, outcome measures, and follow-up durations. Such methodological variability reduces the certainty of pooled evidence,

complicates comparison between studies, and limits the development of standardized evidence-based treatment algorithms. Moreover, relatively few randomized controlled trials directly compare multimodal therapeutic strategies despite their increasing adoption in contemporary clinical practice. Future research should therefore prioritize standardized outcome measures, longer follow-up periods, and head-to-head comparative studies evaluating integrated treatment protocols rather than individual procedures alone. [10-24,29-35]

Another important observation is that technological innovation alone does not necessarily translate into improved clinical outcomes. Emerging approaches-including mesenchymal stem cell-derived extracellular vesicles, laser-assisted drug delivery, combination laser strategies, biomarker-guided treatment, advanced imaging, and artificial intelligence-assisted scar assessment-offer considerable biological and clinical potential. Nevertheless, successful implementation of these technologies depends on rigorous clinical validation, standardized treatment protocols, reproducible manufacturing methods, appropriate patient selection, and integration within evidence-based therapeutic strategies. Consequently, future progress is likely to depend less on the introduction of individual technologies than on optimizing how existing therapeutic modalities are selected, combined, and sequenced. [23-35]

The transition toward precision medicine represents one of the most promising future directions in scar management. Advances in molecular biomarkers, scar phenotyping, regenerative medicine, imaging technologies, and artificial intelligence may improve prediction of treatment response and facilitate personalized therapeutic decision-making. However, these approaches remain largely investigational and require robust prospective validation, external validation of predictive models, and international standardization before routine clinical implementation can be recommended. [24,25,31-35]

Overall, the evidence synthesized in this review indicates that successful scar management depends less on individual therapeutic technologies than on appropriate patient selection, optimal treatment timing, and biologically informed integration of complementary interventions. Rather than seeking a universally superior therapy, future clinical practice should focus on delivering the right intervention to the right patient at the right stage of scar maturation. This personalized, mechanism-based approach is likely to define the next generation of evidence-based scar management. [7-9,24,29-35]

4. Conclusions

Contemporary scar management has evolved from empirical treatment toward biologically informed, evidence-based, and personalized therapeutic strategies. Advances in the understanding of wound healing, fibrosis, mechanobiology, and tissue regeneration have fundamentally reshaped therapeutic decision-making, emphasizing treatment selection according to scar phenotype, stage of maturation, biological activity, and patient-specific characteristics rather than a one-size-fits-all approach. [6-9,35]

Current evidence indicates that no single therapeutic modality adequately addresses the biological complexity of pathological scarring. Instead, the greatest clinical benefit is achieved through individualized multimodal treatment strategies integrating conservative therapy, intralesional pharmacotherapy, regenerative interventions, surgical revision, and laser-based technologies according to the dominant biological mechanisms driving scar remodeling. [7-9,15-24,29-32,35]

Emerging approaches-including regenerative medicine, extracellular vesicles, laser-assisted drug delivery, molecular biomarkers, advanced imaging, and artificial intelligence—have the potential to further improve treatment personalization and optimize long-term clinical outcomes. However, their successful implementation will require standardized treatment protocols, robust comparative clinical trials, validation of predictive biomarkers, and integration into evidence-based therapeutic algorithms. [23-35]

Ultimately, the future of scar management lies not in identifying a universally superior therapy but in delivering the right intervention to the right patient at the right stage of scar maturation. Precision medicine, biologically guided treatment selection, and rational integration of complementary therapeutic modalities are likely to define the next generation of evidence-based scar management. [7,24,27,29-35]

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