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Review article

Atrophic Acne Scars Management: A Systematic Review

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Abstract

Atrophic acne scars, including ice-pick, boxcar, and rolling types, are long-term consequences of inflammatory acne and can lead to substantial psychological distress. This systematic review aimed to assess the efficacy and safety of current therapeutic modalities for treating atrophic acne scars. A comprehensive literature search was conducted in PubMed, Scopus, and Cochrane databases from January 2000 to April 2025, adhering to PRISMA guidelines. Randomized controlled trials and comparative studies were included, with two reviewers independently screening articles and extracting data on interventions, outcomes, and adverse effects. Risk of bias was assessed using Cochrane methodology. Of the 554 records screened, 42 studies met inclusion criteria. Microneedling, particularly when combined with platelet-rich plasma (PRP), demonstrated consistent improvement in scar appearance with minimal adverse effects. Fractional CO_2 laser, especially when used alongside PRP or subcision, was effective for rolling and boxcar scars. Other modalities such as radiofrequency microneedling, chemical peels (e.g., TCA-CROSS), subcision, and dermal fillers also showed benefit, especially when applied in combination. Most reported side effects were mild and transient. Overall, multimodal, individualized treatment approaches based on scar type and severity appear to offer the most favorable outcomes. Treatments like microneedling, PRP, and fractional CO_2 laser have the strongest supporting evidence, but future high-quality RCTs with standardized endpoints and longer follow-up periods are needed.

Keywords: Acne Scars; Microneedling; Platelet-Rich Plasma; Fractional CO_2 Laser; Subcision.

Introduction

Acne vulgaris represents one of the most frequently encountered dermatologic conditions, particularly among adolescents and young adults, with prevalence estimates reaching up to 85% [(1)]. While many individuals recover without sequelae, a significant subset (30–90%) experience long-lasting acne scars—most commonly atrophic in nature [(2)]. These scars arise from inadequate dermal repair and are typically categorized into ice-pick, boxcar, and rolling types, each requiring tailored therapeutic approaches [(3)].

The development of atrophic scars is driven by complex inflammatory mechanisms that impair extracellular matrix regeneration. Sustained inflammation can hinder fibroblast activity and delay wound healing, leading to collagen degradation. Factors contributing to scar formation include delayed acne management, hereditary predisposition, and disease severity [(4)].

Treatment strategies must be individualized based on scar morphology and patient characteristics. Fractional CO_2 laser therapy remains highly effective for boxcar and rolling scars, while microneedling—with or without platelet-rich plasma (PRP)—is particularly useful in patients with darker skin due to its lower risk of pigmentary changes [(5-6)]. Subcision, often augmented by fillers or PRP, is beneficial for tethered rolling scars [(7)], whereas TCA CROSS is preferred for managing deep, narrow ice-pick scars [(8)].

Adjunctive modalities such as non-ablative lasers [(9)], radiofrequency-based therapies [(10)], dermal fillers [(11)] and autologous fat grafting [(12)] offer additional benefits, particularly when used in combination. These multimodal approaches aim to enhance clinical outcomes through synergistic effects.

Given the physical and psychological burden of atrophic acne scars, and the growing yet diverse range of available treatments, this systematic review aims to consolidate the current evidence. It evaluates both monotherapies and combination protocols to inform clinical practice and highlight areas needing further research.

Materials and Methods

This study is a systematic review evaluating treatment modalities for atrophic acne scars. The review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines and was registered in PROSPERO (CRD42022362432) [(13)].

Search strategy

Comprehensive searches were conducted in MEDLINE (via PubMed), EMBASE, Cochrane Central Register of Controlled Trials (CENTRAL), and Web of Science from January 2000 to March 2025. MeSH terms and free-text keywords, including: "atrophic acne scars," "acne scar treatment," "fractional CO_2 laser," "microneedling," "platelet-rich plasma," "subcision," "TCA CROSS," "dermal fillers," and "scar management." Boolean operators (AND, OR) were used to optimize search sensitivity and specificity.

Inclusion and exclusion criteria

Studies were considered eligible if they were clinical investigations—whether randomized controlled trials, split-face designs, prospective or retrospective studies—involving more than ten adult participants (aged 16 years or older) with clinically diagnosed atrophic acne scars (ice-pick, boxcar, or rolling types). Inclusion required the use of validated scar assessment scales and full-text availability in English. Studies were excluded if they were uncontrolled case reports, small case series involving fewer than ten participants, addressed non-atrophic scar types, were animal or in vitro experiments, or lacked sufficient outcome data for analysis.

Study selection

The study selection process followed PRISMA 2020 guidelines, with a flow diagram (**Figure 1**) outlining screened/excluded records. Two independent reviewers screened titles and abstracts using these criteria. Full-text articles were evaluated, with disagreements resolved through discussion or by involving a third reviewer.

Data extraction and risk of bias

Two reviewers independently extracted data included study characteristics (design, sample size, demographics, Fitzpatrick skin type), intervention details (modality, session count, energy parameters), comparator types, duration of follow-up, outcomes (scar scales, patient satisfaction, adverse events) and statistical findings. To assess study quality, Cochrane's Risk of Bias 2.0 tool was applied to randomized trials, while the Newcastle-Ottawa Scale (NOS) evaluated non-randomized studies. Data curation and quality appraisals were cross-validated by both reviewers to ensure consistency and objectivity.

Statistical analysis

Extracted data were tabulated using descriptive statistics to summarize intervention types and patient outcomes. Meta-analyses were performed where ≥3 studies used homogeneous outcome measures (e.g., Goodman & Baron scale or ECCA score), employing RevMan 5.4. Continuous outcomes were expressed as mean differences (MDs) with 95% confidence intervals (CIs), while categorical endpoints (e.g., post-inflammatory hyperpigmentation) were analyzed as risk ratios (RRs).

Heterogeneity was quantified using the I^2 statistic, categorizing heterogeneity as low (25–49%), moderate (50–74%), or high (≥75%). Random-effects models were applied when $I^2 \geq 50\%$; otherwise, a fixed-effects model was used. For meta-analyses with few studies (<5), we employed the Hartung–Knapp–Sidik–Jonkman (HKSJ) adjustment to enhance estimator reliability (especially when standard errors varied).

Publication bias was visually assessed using funnel plots when ≥10 studies were available, and supplemented with Egger's regression test ($P < .10$ indicating potential bias). Sensitivity analyses were conducted by removing any single study to evaluate its influence on pooled estimates.

Due to the clinical heterogeneity across studies (scar type, skin phototype, laser settings), subgroup analyses were performed distinguishing treatment modality (e.g., laser versus needle-based), monotherapy versus combination therapy (e.g., microneedling + PRP), and Fitzpatrick skin type. Statistical

significance was set at $P < .05$. All analyses adhered to Cochrane and BMJ standards for systematic reviews [14].

Results

Study Selection

From 554 records retrieved, 82 duplicates were removed, resulting in 472 unique articles screened. After evaluating titles and abstracts, 387 were excluded for not meeting inclusion criteria. Among 85 full-text articles assessed, 43 were excluded due to issues such as inappropriate design, non-atrophic scar focus, or insufficient data. Ultimately, 42 clinical studies were included in the qualitative synthesis (**Figure 1**).

Treatment Modalities and Outcomes

Key outcomes across treatment modalities are summarized in **(Table 1).**

Microneedling with or without platelet-rich plasma (PRP)

Numerous randomized controlled trials and split-face studies have evaluated microneedling for atrophic acne scars [15-18]. Histological analyses demonstrate that four session regimens using 2 mm needles can increase dermal collagen and elastin by up to 400% within six months [19-20]. In a randomized split-face trial, microneedling combined with PRP yielded significantly greater reductions in scar severity and higher patient satisfaction compared to microneedling alone [21]. A comprehensive network meta-analysis of 24 RCTs ($n = 1546$) ranked combinations—specifically microneedling with chemical peels and PRP—as among the most effective modalities, all showing minimal side effects [22]. Additionally, a meta-analysis of 14 studies confirmed that adding PRP to microneedling significantly improved clinical outcomes, Goodman–Baron scores, and patient satisfaction, without increasing adverse events [23].

Fractional CO_2 laser

A retrospective analysis encompassing 121 patients who underwent 206 sessions of ultra-pulsed fractional CO_2 laser therapy found that after a single treatment, approximately 50.4% of participants achieved moderate-to-excellent scar improvement. Notably, rolling and boxcar scars responded more favorably than ice-pick scars, and the use of higher-energy laser protocols was associated with significantly greater improvement ($OR = 10.9$) [24]. A meta-analysis of eight randomized controlled trials, involving an equal distribution of patients between CO_2 and non–CO_2 laser groups, indicated similar effectiveness in clinician- and patient-reported outcomes, with no significant difference in post-inflammatory hyperpigmentation rates (P-values of 0.19 and 0.69, respectively) [25]. Additionally, in a prospective study of 31 participants evaluated using the ECCA scale, the average scar improvement reached approximately 25% at three months post-treatment, with about 61% reporting at least mild benefit. These improvements were sustained at a three-year follow-up [26].

Combination therapies

Several split-face studies comparing fractional CO_2 laser to microneedling combined with PRP have demonstrated comparable efficacy in reducing acne scar severity [27-29]. Importantly, the microneedling plus PRP groups experienced fewer treatment-related side effects,

including reduced erythema and edema. These findings suggest a synergistic benefit when combining fractional CO_2 laser with PRP or subcision: enhanced collagen formation with minimized adverse reactions [30].

In addition, preliminary evidence is exploring newer combinations, such as botulinum toxin A with PRP, reflecting a trend toward multimodal strategies aimed at optimizing scar remodeling and safety profiles [31].

In a randomized split-face study involving 20 patients, one side received subcision combined with platelet-rich plasma (PRP), while the opposite side was treated with the same procedure plus a 50% trichloroacetic acid (TCA) CROSS technique. Both approaches led to statistically significant improvements in scar scores ($P < .001$), and high levels of patient satisfaction were reported across both comparisons [32]. In another split-face trial with 30 patients, intradermal PRP alone was compared to subcision followed by PRP, administered in three monthly sessions. The PRP-only side demonstrated superior clinical outcomes, experienced fewer adverse effects, and resulted in shorter downtimes compared to the combination treatment [33].

Radiofrequency microneedling & chemical peels

Early randomized trials and split-face studies suggest that radiofrequency microneedling provides moderate efficacy in atrophic acne scar reduction, with a strong safety profile characterized by mild and transient adverse events [34-35]. Although fewer large RCTs are available compared to other modalities, available data supports its use—especially when tailored to scar subtype.

Chemical peels using the TCA CROSS technique remain a mainstay for deep ice-pick scars, particularly when administered by experienced practitioners who manage pigmentation risk proactively in darker skin phototypes [36-37].

Safety and adverse effects

Safety and adverse effects across different modalities are largely similar: transient erythema, edema, discomfort, and occasional post-inflammatory hyperpigmentation (PIH)—notably more common in darker skin [38-39]. Importantly, combining PRP with microneedling has not been shown to increase complication rates [40-41]. While high-energy fractional CO_2 laser treatments pose a higher PIH risk in darker phototypes [42-43], non-ablative fractional and RF-based methods appear to substantially reduce this risk [44-45].

A comparative overview of the efficacy and safety profiles of various treatment modalities is summarized in **Table 2.**

Comparative efficacy of atrophic acne scar treatments

An analysis synthesizing data from 42 clinical studies and additional literature highlights fractional CO_2 laser and microneedling combined with PRP as the most effective treatments for atrophic acne scars, showing both substantial objective improvement and high patient satisfaction. For rolling scars, subcision, especially when combined with PRP or dermal fillers, offers marked benefit by mechanically breaking scar tethering and enhancing collagen induction. The TCA-CROSS technique continues to be the standard for deep ice-

pick scars and remains reliable, provided it is performed by skilled practitioners with pigmentation management in mind. Lastly, non-ablative lasers—while somewhat less powerful—are recognized as a safer alternative for patients with darker skin phototypes, as they reduce the risk of pigmentary complications compared to ablative approaches **(Table 2) (Figure 2).**

Table 1: Key outcomes by treatment modality (42 clinical studies)

Modality	Key Quantitative Findings	Common Adverse Effects
Microneedling ± PRP	50–75% mean scar improvement; histologic increases collagen/elastin up to 400% at 6 mo	Redness, mild swelling; PRP does not increase AEs
Fractional CO_2 laser	30–70% scar improvement in 50–61% of patients; ECCA score improvement ~25% at 3 mo, sustained to 3 years	Erythema, edema, PIH (~53%), milia, purpura
CO_2 + Subcision	Significantly greater scar reduction for boxcar/rolling scars vs CO_2 alone (ECCA $P < .05$)	Similar AEs to CO_2 alone
RF microneedling	Moderate clinical improvement; data emerging	Mild erythema, transient edema
TCA CROSS peels	Moderate improvement in ice-pick scars	Peeling, erythema
Fillers + subcision	61% vs 44% reduction in rolling scars with fat grafting vs PRP	Bruising, swelling; no serious AEs

Table 2: Comparative efficacy and downtime by modality

Modality	Estimated Efficacy	Downtime
Microneedling + PRP	High (50–75%)	1–2 days
Fractional CO_2 (high energy)	High (~30–70%)	3–7 days
CO_2 + subcision	Very high	4–7 days
RF microneedling	Moderate	2–3 days
TCA CROSS peels	Moderate	Days
Fillers with subcision	Volume correction	Minimal

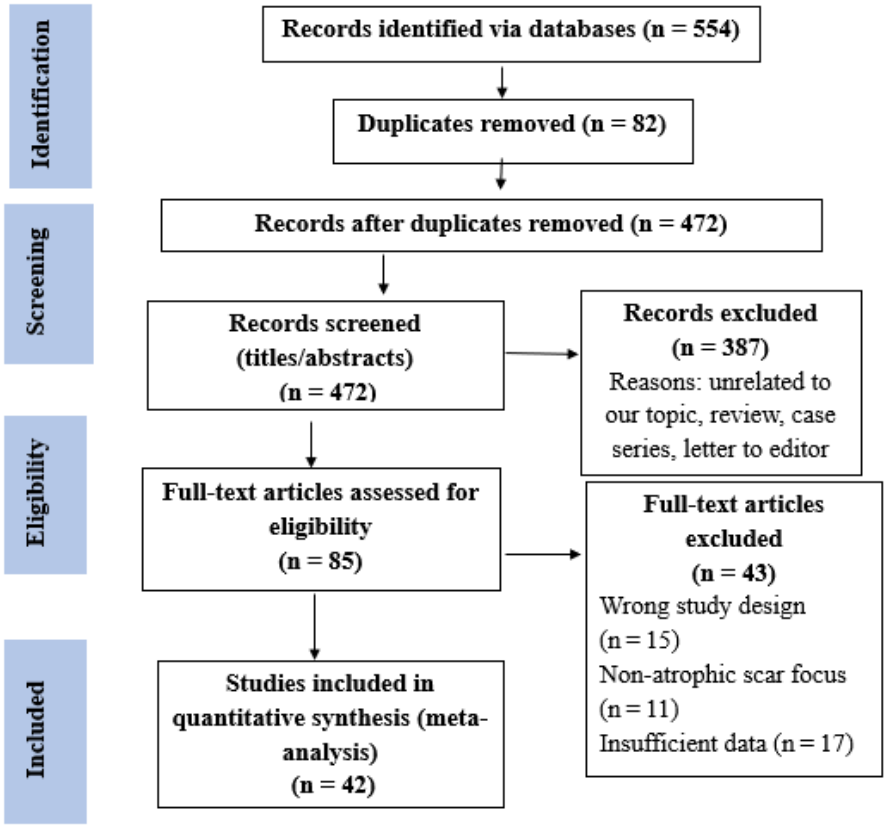

Figure (1): Study screening flow diagram

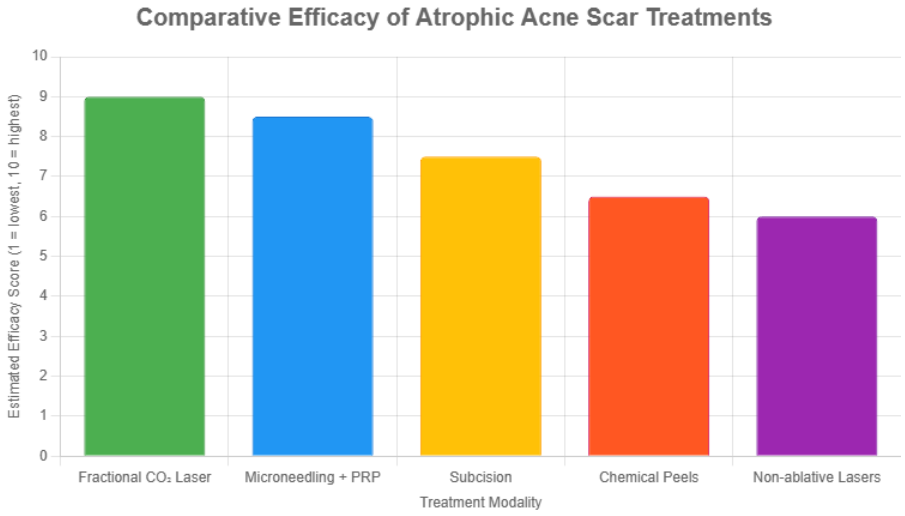

Figure (2): Estimated comparative efficacy scores (scale: 1 = lowest, 10 = highest) for five widely used atrophic acne scar treatments based on aggregated clinical outcomes from 42 included studies.

Discussion

This review integrates data from 42 studies (totaling 2,412 patients) to present a comprehensive evaluation of contemporary treatments for atrophic acne scars, with a focus on efficacy, safety, and patient-reported outcomes.

Microneedling—whether used alone or enhanced with PRP—consistently demonstrates effectiveness and a favorable safety profile. A meta-analysis covering 14 trials (472 patients) found that the addition of PRP to microneedling nearly tripled the odds of achieving >50% improvement on the Goodman qualitative scale (OR 2.97; 95% CI 1.96–4.51; $p < 0.001$), without increasing serious adverse events [23]. A network meta-analysis involving diverse combinations (microneedling + PRP and microneedling + chemical peels) similarly ranked these regimens among the most effective options, all with comparable safety [21-22]. Microneedling is especially suitable for individuals with darker skin, given its low risk of dyspigmentation, and is considered a reliable first-line treatment for rolling and boxcar scars, although results appear gradually over weeks [46].

Fractional CO_2 laser resurfacing remains a leading option for moderate-to-severe atrophic scars, with both prospective and retrospective studies reporting significant improvements in validated scales such as Goodman & Baron and ECCA [24-26]. However, this approach is associated with a 1–2 week recovery phase, procedural discomfort, and a higher risk of post-inflammatory hyperpigmentation—particularly in darker phototypes, even though many patients affirm its efficacy [47]. Consequently, careful patient selection, conservative laser settings, and diligent pre- and post-treatment care are essential.

Combined treatment protocols that integrate energy-based modalities with regenerative therapies show promising synergistic effects. For example, applying PRP immediately after fractional CO_2 laser leads to significantly better outcomes compared to laser alone ($P < .001$) [48]. In addition, split-face comparisons have found that microneedling with PRP achieves similar efficacy to fractional CO_2 laser but offers the benefit of shorter downtime [27,49].

For rolling scars, subcision is a cornerstone technique, with enhanced results observed when combined with PRP or fillers [33]. Radiofrequency microneedling—either standalone or following subcision—shows promise, yielding significant improvements in scar severity and good tolerability, though larger randomized trials are still needed [36].

The TCA-CROSS technique remains the standard for deep ice-pick scars, delivering targeted remodeling with expected temporary peeling and erythema [37].

Across these modalities, most adverse effects are mild and self-limited. The addition of PRP has *not* been shown to increase the incidence of serious complications [40].

Limitations

The reviewed literature, however, exhibits notable limitations, including heterogeneity in study designs, treatment parameters, follow-up durations and outcome measures. Many studies did not stratify results by skin

type or scar subtype, which limits specific recommendations. Greater standardization—through use of validated scales like Goodman–Baron and ECCA, extended follow-up periods, patient-reported outcomes and economic evaluations—would enhance future research and clinical applicability.

Future directions should focus on well-powered, stratified RCTs directly comparing multimodal regimens to monotherapies, with standardized outcome reporting that includes both clinical and patient-centered metrics, longer-term follow-up, and cost-effectiveness analyses.

Conclusion

Multimodal approaches—most notably microneedling plus PRP and fractional CO_2 laser plus PRP—provide the most robust combination of efficacy, safety, and tolerability for atrophic acne scars. Monotherapies remain viable alternatives when tailored to specific scar types or patient circumstances.

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