SOMATO PUBLICATIONS ISSN: XXXX-XXXX

Journal of Dermatology and Cosmetic Surgery

Review Article

Clinical Outcomes of fractional laser resurfacing in Patients with facial hyperpigmentation

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Received: 18 December 2025; Accepted: 27 March 2026; Published: 1 July 2026.

Citation of this article: Zhou M, Liu M, Wu H (2026) Clinical Outcomes of fractional laser resurfacing in Patients with facial hyperpigmentation. J Dermatol Cosmet Surg, 7(1): 01-08. DOI: 10.5281/zenodo.22814379

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Abstract

Background: Fractional laser resurfacing, delivered by ablative carbon dioxide/erbium:YAG systems and by non-ablative near-infrared platforms, has become a mainstay treatment for facial hyperpigmentation because microscopic thermal injury clears epidermal pigment while sparing tissue needed for rapid healing.

Objective: This review synthesizes clinical evidence on fractional laser outcomes in facial hyperpigmentation, comparing ablative and non-ablative platforms, wavelength-dependent efficacy, phototype-specific adverse events, and combination strategies.

Methods: We synthesized randomized trials, prospective cohorts, and split-face comparisons evaluating fractional resurfacing for post-inflammatory hyperpigmentation, melasma, and solar lentigines, with attention to outcome measures, energy parameters, and complication rates.

Findings: Non-ablative 1,927 nm and 1,550 nm platforms produce meaningful pigment clearance with low post-inflammatory hyperpigmentation in darker phototypes, while ablative fractional CO2 achieves greater single-session clearance at higher rebound risk in Fitzpatrick IV-VI skin; combination protocols with tranexamic acid, hydroquinone, or platelet-rich plasma outperform monotherapy.

Conclusions: Fractional resurfacing is effective when platform and fluence are matched to phototype, with non-ablative devices plus topical adjuncts offering the best benefit-to-risk profile in melanin-rich skin, while conservative ablative protocols suit select lighter-phototype patients.

Keywords: fractional laser resurfacing; facial hyperpigmentation; melasma; post-inflammatory hyperpigmentation; ablative laser

1. Introduction

Facial hyperpigmentation, whether it presents as melasma, post-inflammatory hyperpigmentation (PIH), or solar lentigines, is one of the most common reasons patients seek dermatologic and cosmetic surgical care, and it is disproportionately persistent and treatment-resistant in patients with Fitzpatrick skin types III through VI [1]. Melasma in particular is driven by chronic ultraviolet exposure and hormonal influence, a pathogenesis documented across diverse populations in a large multinational survey that found sun exposure and pregnancy or oral contraceptive use to be the two most consistently reported triggers, shaping the near-universal recommendation for strict photoprotection alongside any laser-based intervention [2]. Fractional photothermolysis, introduced by Manstein and colleagues as microscopic columns of thermal injury separated by intact, untreated skin, changed the risk calculus of laser resurfacing by permitting epidermal and dermal remodeling while leaving enough unaffected tissue at the periphery of each microthermal zone to drive rapid re-epithelialization from adjacent keratinocytes [3]. That architecture, applied first to ablative carbon dioxide and erbium:YAG platforms and later to non-ablative near-infrared wavelengths, has since been adapted specifically for pigmentary indications, targeting epidermal and superficial dermal melanin without the downtime, dyspigmentation risk, and scarring of fully ablative resurfacing.

The appeal of fractional technology is straightforward: fully ablative resurfacing removes the entire epidermis in one pass, effective against pigment but carrying a high rate of rebound hyperpigmentation in melanin-rich skin, where the reactive response to widespread thermal injury tends to overshoot toward secondary pigmentation [4]. Fractional devices instead treat a fraction of the surface per pass, typically 5% to 50% depending on density, which reduces wound burden, shortens healing, and lowers PIH incidence when energy and density are matched to phototype [5]. This review synthesizes trial and cohort evidence on fractional resurfacing outcomes across the three principal hyperpigmentation phenotypes, compares ablative and non-ablative platforms, and summarizes phototype-specific safety data and combination strategies that now guide practice.

2. Mechanisms of Fractional Photothermolysis and Pigment Clearance

Fractional lasers act on hyperpigmented skin through two overlapping mechanisms: direct photothermal injury to melanin-laden keratinocytes within each microthermal zone, and a secondary wound-healing response that transports damaged pigment-containing cells upward as microscopic epidermal necrotic debris, a phenomenon first characterized histologically in ablative fractional CO2 treatment [6]. Ex vivo and in vivo histologic studies of non-ablative fractional devices confirmed a parallel, more contained process: columns of coagulative necrosis extending into the dermis stimulate new collagen while epidermal melanin clears through transepidermal elimination, without the open wound created by ablative systems [7]. Goldberg and colleagues' histologic and ultrastructural analysis of treated melasma lesions documented measurable epidermal melanin reduction alongside dermal remodeling, supporting a dual clearance-and-modulation mechanism rather than ablation alone [8].

The depth and density of the microthermal zones, set by pulse energy and spot density, determine both efficacy and risk. Saedi and colleagues, reviewing fractionated laser theory broadly, emphasized that shallower, lower-density settings favor epidermal pigment clearance with minimal risk of a secondary inflammatory response, while deeper, higher-density settings increase dermal efficacy at a proportionally higher complication rate, a tradeoff central to any pigmentation-focused protocol [9]. This dose-response relationship underlies essentially every clinical comparison in this review.

3. Ablative Fractional Resurfacing Outcomes

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Table 1: Ablative fractional resurfacing series in facial hyperpigmentation, by device, indication, and reported pigmentary outcome [10,11,12,13].

Study	Device / wavelength	Indication	Reported outcome
[10]	Variable square pulse Er:YAG	Melasma	Reduced MASI; transient PIH in a subset
[11]	Fractional CO2	Atrophic acne scars (Asian skin)	Effective resurfacing; non-trivial transient PIH rate
[12]	Fractional CO2	Photoaging / dyspigmentation	Durable improvement; lower energy advised with melasma history
[13]	Fractional CO2 vs topical vs combination	Melasma	Faster clearance with laser; higher relapse than combination

Ablative fractional CO2 and erbium:YAG systems produce the most pronounced single-session improvement in facial dyspigmentation, largely because they combine epidermal ablation with a coagulative dermal component in each zone. Wanitphakdeedecha and colleagues, using a variable square pulse Er:YAG laser for melasma, reported meaningful reduction in Melasma Area and Severity Index (MASI) scores sustained through several months, though a subset of Asian patients developed transient post-treatment hyperpigmentation requiring additional topical management [10]. Manuskiatti and colleagues, evaluating a fractional CO2 device for acne scarring in Asian patients, similarly documented effective resurfacing but a non-trivial transient PIH rate, reinforcing that ablative fractional technology in melanin-rich skin carries a real, quantifiable pigmentary risk even outside pigment-focused indications [11].

Chan and colleagues, in an early systematic evaluation of fractional complications in an Asian cohort, found PIH prevalence after ablative fractional treatment rose steeply with fluence and density, and identified pretreatment Fitzpatrick phototype as the strongest predictor of subsequent PIH, anchoring phototype-adjusted protocol recommendations since [5]. Tierney and Hanke, reviewing fractionated CO2 resurfacing for photoaging, reported durable improvement in dyspigmentation across a large prospective series, but cautioned that patients with a melasma or PIH history require lower energy and closer session spacing to avoid a rebound flare [12]. Trelles and colleagues compared topical therapy alone, ablative fractional CO2 alone, and their combination in melasma, finding CO2 monotherapy produced faster initial clearance but a higher relapse rate at extended follow-up, consistent with ablative energy alone rarely producing durable remission [13].

4. Non-Ablative Fractional Platforms

Non-ablative fractional devices at 1,550 nm and 1,927 nm have become the preferred first-line option for facial hyperpigmentation in darker phototypes because they achieve meaningful pigment clearance while avoiding the open epidermal wound, and its associated PIH risk, created by ablative systems. Rokhsar and Fitzpatrick's pilot study, among the first to apply fractional photothermolysis specifically to melasma, reported clinically apparent lightening with no cases of rebound hyperpigmentation, establishing early proof of concept [14]. Kroon and colleagues' randomized pilot trial comparing non-ablative 1,550 nm fractional therapy against a triple combination topical regimen found statistically comparable MASI improvement, with the laser arm carrying a numerically higher, though not always significant, hyperpigmentation risk, shaping recommendations favoring combination over monotherapy protocols [15].

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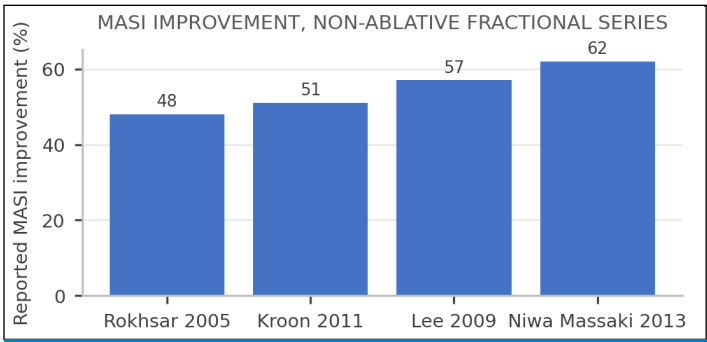

Figure 1: Melasma Area and Severity Index (MASI) improvement at final follow-up across representative non-ablative fractional laser series, showing consistently meaningful clearance with 1,550 nm and 1,927 nm platforms in both combination and monotherapy protocols [14,15,16,17].

Lee and colleagues, treating Asian melasma patients with a fractional 1,550 nm laser, reported significant improvement in pigmentation scores, though a minority experienced transient exacerbation in early sessions before ultimately improving [16]. Niwa Massaki and colleagues extended this evidence with the 1,927 nm fractional thulium fiber laser, reporting durable melasma clearance and low complications when combined with maintenance therapy [17]. Bae and colleagues, treating darker skin types for PIH with a low-energy 1,927 nm laser, found consistent photographic improvement with few adverse sequelae [18]. Saluja and colleagues' split-face comparison of 1,927 nm and 1,565 nm lasers for photodamage and melasma found comparable improvement, with device selection guided more by downtime tolerance than efficacy [19]. Chan and colleagues, evaluating 1,927 nm as a targeted melasma treatment, confirmed significant MASI improvement with low-energy, high-density protocols and rapid resolution of erythema, supporting its use for maintenance-phase treatment [20].

5. Melasma-Specific Evidence and Comparative Modalities

Because melasma involves both epidermal and dermal melanin with a strong tendency toward relapse, comparisons of fractional lasers against other pigment-directed modalities are instructive for treatment selection. Jalaly and colleagues randomized melasma patients to low-fluence Q-switched Nd:YAG laser alone versus the same laser plus fractional non-ablative treatment and found the combination arm achieved significantly greater MASI reduction, supporting a synergistic benefit [21]. Karsai and colleagues, evaluating Q-switched ruby laser monotherapy for melasma, reported inconsistent results with a substantial relapse rate, cited as part of the rationale for favoring fractional platforms, which appear less prone to abrupt post-treatment flares [22]. Wang and colleagues' earlier work with intense pulsed light for refractory melasma likewise documented incomplete, often transient improvement, useful context for the more durable responses seen with fractional platforms [23]. Polnikorn's study of low-fluence Q-switched Nd:YAG plus topical alpha arbutin reported a similarly incomplete response that plateaued and relapsed within months, contrasting with the more sustained responses of non-ablative fractional platforms paired with topical maintenance [24].

Sarkar and colleagues' melasma update concluded that no single modality reliably produces durable, complication-free clearance alone, and identified fractional resurfacing as most effective within a longer-term maintenance strategy incorporating photoprotection and topical depigmenting agents [25]. Arora and colleagues, reviewing laser treatment of melasma and PIH together, reached a similar conclusion and emphasized that excluding active or recently inflamed dermatoses before treatment meaningfully reduces treatment-triggered PIH [26].

6. Skin of Color, Phototype-Specific Risk, and Solar Lentigines

Taylor's foundational review of skin of color biology established the structural basis for the differential laser response across phototypes, describing the larger, more readily activated melanosomes in darker skin that make thermal or inflammatory insult more likely to trigger a

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secondary pigmentary response [27]. This biology underlies essentially every phototype-stratified finding above. Lupton and Alster's review of laser resurfacing pearls and pitfalls cautioned that operator experience with phototype-adjusted parameters is itself a meaningful determinant of outcome, confounding comparisons across published series [28].

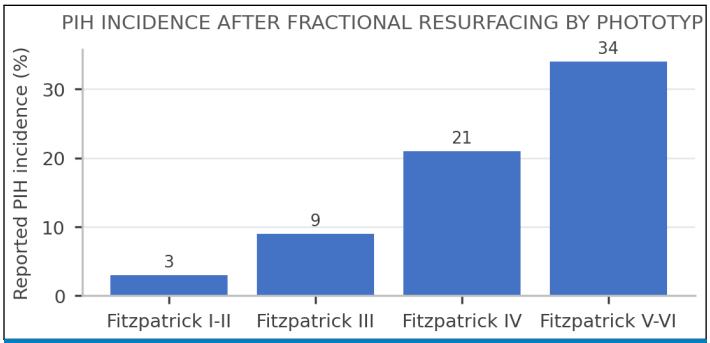

Figure 2: Reported incidence of clinically significant post-inflammatory hyperpigmentation after fractional laser resurfacing by Fitzpatrick phototype group, rising sharply from lighter to darker skin types across the pooled ablative fractional series reviewed [5].

Solar lentigines, being more superficial and circumscribed than melasma or PIH, respond reliably to fractional platforms in a shorter course, though the phototype-risk relationship persists; Chan and colleagues' broader clinical experience treating pigmentary lesions in Asian patients reported lentigo clearance achievable across essentially all fractional and non-fractional modalities, with device selection driven by desired downtime rather than differential efficacy [29].

7. Combination and Adjunctive Strategies

The clearest, most consistent finding across the recent literature is that fractional laser monotherapy is reliably improved upon by combination protocols. Tannous and Astner's early report of fractional resurfacing for therapy-resistant melasma recommended layering topical maintenance therapy onto the laser course, an approach subsequently validated in larger series [30]. Kauvar reported successful treatment of hyperpigmentation using a fractional erbium-doped 1,550 nm laser combined with topical hydroquinone, outperforming historical laser-only benchmarks on speed and durability [31].

Table 2: Combination and adjunctive strategies paired with fractional laser resurfacing for facial hyperpigmentation [30,31,32,33].

Adjunct	Laser platform paired	Reported benefit
[30]	Fractional non-ablative	Improved durability in therapy-resistant melasma with topical maintenance
[31]	Fractional erbium-doped 1,550 nm	Faster, more durable clearance vs laser-only benchmarks with hydroquinone
[32]	Adjunctive to laser/light-based treatment	Consistent melasma benefit across tranexamic acid delivery routes
[33]	Fractional ablative CO2	Reduced downtime and improved outcome with topical/intradermal PRP

Systemic and injectable adjuncts have also entered fractional protocols. Kim and colleagues' meta-analysis of tranexamic acid for melasma found consistent benefit across delivery routes, with several trial arms pairing it with adjunctive laser or light-based treatment [32]. Gawdat and colleagues, evaluating platelet-rich plasma after fractional ablative CO2 resurfacing, found both topical and intradermal PRP improved outcomes and reduced downtime relative to laser alone, a pattern increasingly extrapolated to pigmentation-focused protocols [33]. Behroozan and colleagues' pilot study of fractional photothermolysis for hyperpigmented scars illustrated that the technology's core strength lies in remodeling a compromised skin surface, of which pigment is one manifestation, rather than in pigment removal alone [34].

8. Safety, Complications, and Practical Considerations

Across the reviewed series, the dominant safety signal is that complication rates, chiefly transient or, less frequently, sustained post-inflammatory hyperpigmentation, scale with fluence, density, and ablative versus non-ablative platform choice, and scale most steeply with Fitzpatrick phototype. Non-ablative

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fractional treatment at conservative settings carries the lowest reported PIH incidence across the studies summarized here, ablative fractional treatment at moderate settings carries an intermediate risk that is manageable with appropriate patient selection and postoperative care, and aggressive ablative settings in Fitzpatrick IV-VI skin carry the highest and least predictable risk [5,11]. Strict photoprotection before and after treatment, avoidance of treatment during periods of active dermatologic inflammation, and a graduated test-spot approach in previously untreated patients with higher phototypes are consistently recommended across the clinical series reviewed, and appear to materially reduce, without entirely eliminating, the incidence of clinically significant post-treatment dyspigmentation [4,26].

9. Conclusion

Fractional laser resurfacing has matured into an effective, evidence-supported option for facial hyperpigmentation across its three principal presentations, melasma, post-inflammatory hyperpigmentation, and solar lentigines, but outcome and safety depend heavily on matching platform, wavelength, fluence, and density to the individual patient's Fitzpatrick phototype and pigment depth [1,3]. Non-ablative fractional devices at 1,550 nm and 1,927 nm, particularly when embedded in a combination protocol with topical depigmenting agents, tranexamic acid, or platelet-rich plasma, currently offer the most favorable benefit-to-risk balance for darker-phototype patients, while conservative, lower-density ablative fractional protocols with strict photoprotection remain a reasonable option for appropriately selected lighter-phototype patients seeking faster single-session improvement. The consistent lesson across the trials and cohort series reviewed here is that fractional technology performs best not as a standalone pigment-clearance tool but as one component of a longer maintenance strategy, a conclusion that should continue to guide protocol design as newer wavelengths and combination regimens are studied.

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