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Original Research Article

Combined short-pulsed Nd:YAG laser therapy with intralesional triamcinolone injection for hypertrophic scar and keloid treatment

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ABSTRACT

Background: Hypertrophic scars and keloids are difficult to treat and are associated with pain, pruritus, functional impairment, and cosmetic burden. This study evaluated the effectiveness of combining short-pulsed 1064 nm Nd:YAG laser therapy with intralesional triamcinolone injection compared with conventional treatment approaches.
Methods: Between October 2016 and March 2021, 52 patients with hypertrophic scars or keloids were treated at Hautärzte Köln Mülheim, Buchheimer Str. 53-55, 51063 Cologne, Germany, a private dermatology practice specializing in dermatology and laser medicine. Patients were classified into three treatment cohorts according to the treatment received: triamcinolone acetonide (TAC) monotherapy (n=13), TAC plus 5-fluorouracil (5-FU) (n=13), and combination therapy with short-pulsed 1064 nm Nd:YAG laser plus intralesional TAC in the same session (n=26). Laser treatment was performed in Genesis mode using a pulse duration of 0.33 ms, fluence of 4.4 J/cm², and repetition rate of 6 to 8 Hz. Spot size from 4 to 8 mm was adjusted according to scar thickness. Outcomes were assessed using the patient and observer scar assessment scale (POSAS) at baseline and at 3 and 12 months after treatment.
Results: The combination group required fewer treatment sessions than the TAC+ 5-FU group and the TAC monotherapy group (mean 7.2 versus 10.6 and 12.2 sessions, respectively). At 12 months, the combination group showed significantly better POSAS scores than TAC monotherapy on both the patient scale (20.65 versus 30.08, p=0.006) and observer scale (17.81 versus 28.15, p=0.001). No dropouts or serious adverse events occurred.
Conclusions: Short-pulsed 1064 nm Nd:YAG laser combined with intralesional triamcinolone is an effective, safe, and time-efficient treatment for hypertrophic scars and keloids, with superior outcomes compared with steroid monotherapy.

Keywords: Keloid, Hypertrophic scar, Nd:YAG laser, Triamcinolone, 5-Fluorouracil, POSAS

INTRODUCTION

Keloids are the result of aberrant tissue scarring, typically occurring in injured skin, and are caused by the overgrowth of granulation tissue or collagen type III during the healing process.[1] These lesions and hypertrophic scars are caused by cutaneous injury and irritation, including trauma, burns, surgery, vaccination, skin piercing, and bacterial or viral infections.

Superficial injuries that do not reach the reticular dermis never cause keloidal or hypertrophic scarring, suggesting pathological scars result from injury to this skin layer and subsequent aberrant wound healing, characterized by continuous and histologically localized inflammation.[2]

The reticular layer of keloids and hypertrophic scars contains inflammatory cells, increased numbers of stem cells (fibroblasts), newly formed blood vessels, and collagen deposits.[2] Patients with hypertrophic scars and keloids often experience pain, pruritus, restricted motion, and psychological concerns (Figure 1).[3] To address these challenges, a laser system capable of reaching the dermis and targeting blood vessels due to its wavelength was

utilized. The reduction in blood vessels appears to inhibit inflammatory signals transmitted through them.[4]

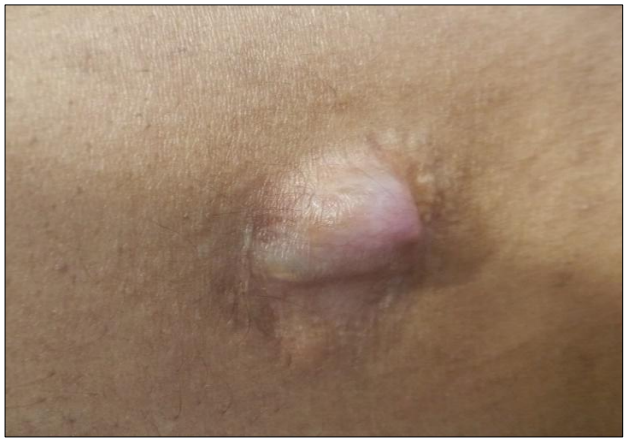

Figure 1: Example of a postoperative keloid.

METHODS

Study design and ethics approval

This retrospective comparative clinical study was conducted at Hautärzte Köln Mülheim, Buchheimer Str. 53-55, 51063 Cologne, Germany, a private dermatology practice specializing in dermatology and laser medicine. Between October 2016 and March 2021, 52 patients with keloids or hypertrophic scars were treated. The study was conducted in accordance with the principles of the Declaration of Helsinki and Good Clinical Practice guidelines. All patients provided written informed consent after receiving comprehensive information about the treatment procedures, potential risks, benefits, and their right to withdraw from the study at any time without affecting their medical care. Diagnosis was confirmed by an independent dermatologist. Exclusion criteria: age under 18 years, loss to follow-up within one year after last treatment, planned surgical interventions near the treatment site, pregnancy, autoimmune diseases, diabetes mellitus, or refusal of steroid injections.

Patient groups

Patients were classified into three treatment cohorts according to the treatment received; group 1 (13 patients): TAC monotherapy, group 2 (13 patients): TAC + 5-FU combination therapy and group 3 (26 patients): Short-pulsed Nd:YAG laser treatment with simultaneous intralesional TAC injection.

Treatment procedures

Steroidal injections

TAC monotherapy group: 40 mg/ml triamcinolone acetonide injected strictly intradermally at 4 mg/cm² (equivalent to 0.1 ml/cm²).

TAC + 5-FU group: 10 mg/cm² (0.2 ml/cm²) intralesional 5-FU (50 mg/ml) combined with 4 mg/cm² (0.1 ml/cm²) triamcinolone acetonide.

Non-ablative laser therapy

A 1064 nm system capable of Q-switched, short-pulsed, and long-pulsed Nd:YAG laser irradiation (Q-Terra Intros Medical Laser, Germany) was used (Figure 2). Parameters were 4.4 J/cm² in Genesis Mode (0.33 ms) at a 6-8 Hz repetition rate. Spot size was adjusted according to scar thickness: <3 mm, 4 mm spot; 3-6 mm, 6 mm spot; and >6 mm, 8 mm spot, provided that the spot size did not exceed the scar borders.

Figure 2: Standard short-pulse Nd:YAG laser treatment parameters.

Treatment continued until skin surface temperature reached 48°C, monitored with infrared camera (Figure 3). If this temperature was reached in <5 seconds, the energy was reduced. Cold air chilling system (Zimmer Cryo 6, Germany) cooled epidermal area after each round. Post-laser, triamcinolone injected intradermally at the same rate.

Treatments were scheduled every two weeks, provided epidermis remained intact and free from inflammation. Between sessions, fusidic acid ointment was applied twice daily. Treatment was concluded when itching and pain had subsided and patients reported satisfaction. All patient data were handled confidentially in accordance with the general data protection regulation (GDPR). No identifiers were used in the analysis; all adverse events were documented and managed.

Evaluation methods

The patient and observer scar assessment scale (POSAS), consisting of two six-item scales (observer/patient), each rated 1-10, was used.[5] Scores: 6=best, and 60=worst.

Patients completed the questionnaires; prior to treatment, three months after final treatment and twelve months after

final treatment. Observer scale was assessed by two independent dermatologists. The primary analysis included all cases. A predefined sensitivity analysis was additionally performed after excluding progressive cases, defined as cases with worsening POSAS values during follow-up.

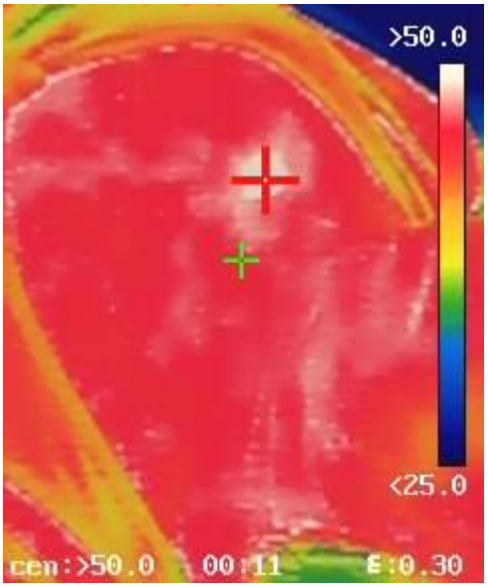

Figure 3: Monitoring skin temperature with a thermal camera.

Statistical analysis

Statistical analysis was performed using statistical package for the social sciences (SPSS) v26 (SPSS Inc., Chicago, USA). The Kolmogorov-Smirnov test was used to assess distribution. One-way analysis of variance (ANOVA) was used to compare the three treatment groups. Fisher's least significant difference (LSD) test was used for post-hoc pairwise comparisons. Paired t-tests were used for within-patient comparisons between time points. A $p<0.05$ was considered statistically significant.

RESULTS

A total of 52 patients were included in the study and allocated to three treatment groups. Group 1 received TAC monotherapy, group 2 was treated with TAC + 5-FU, and group 3 underwent Nd:YAG laser treatment in combination with TAC. No patients were excluded after enrollment, and no patients were lost to follow-up during the 12-month observation period.

Demographic characteristics are summarized in table 1. The overall age of the participants ranged from 18 to 68 years, with a mean age of approximately 38 years, a standard deviation of approximately 13 years, and a median age of approximately 37 years. The age distribution was comparable across the three groups, and no relevant differences in baseline age between the treatment arms were observed.

Of the 52 participants, 33 were female and 19 were male, indicating a predominance of female patients in the study population. The sex distribution was similar across all three groups, and no group showed a marked overrepresentation of either sex.

Table 1: Baseline demographic and clinical characteristics.

Characteristic	Total study population (n=52)
Age, years, mean±SD	38±13
Age, years, median	37
Age range, years	18-68
Female sex, N (%)	33 (63.5)
Male sex, N (%)	19 (36.5)
Fitzpatrick skin types	I-V
Treatment allocation	TAC monotherapy: n=13; TAC + 5-FU: n=13; Nd:YAG laser + TAC: n=26

Treatment characteristics are summarized in Table 2. The Nd:YAG laser + TAC group required fewer treatment sessions than the TAC + 5-FU group and the TAC monotherapy group.

Lower POSAS scores indicate better scar-related symptoms and better scar appearance. Patient-reported POSAS outcomes are summarized in Table 3, including the full analysis with progressive cases and the sensitivity analysis excluding progressive cases. Observer-rated POSAS outcomes are summarized in Table 4. Baseline POSAS scores did not differ significantly between groups on either the patient scale ($p=0.508$) or the observer scale ($p=0.278$).

In the full analysis, patient POSAS differed significantly between groups at 3 months (overall ANOVA $p=0.007$) and 12 months (overall ANOVA $p=0.020$). In LSD post-hoc comparisons, Nd:YAG laser + TAC was significantly superior to TAC monotherapy at 3 months ($p=0.002$) and 12 months ($p=0.006$), but not significantly different from TAC + 5-FU at 3 months ($p=0.109$) or 12 months ($p=0.197$). After excluding progressive cases, the between-group differences in patient POSAS were stronger at both 3 months and 12 months (both overall ANOVA $p<0.001$).

Observer POSAS differed significantly between groups at 3 months (overall ANOVA $p=0.018$) and 12 months (overall ANOVA $p=0.003$). In LSD post-hoc comparisons, Nd:YAG laser + TAC significantly outperformed TAC monotherapy at 3 months ($p=0.014$) and 12 months ($p=0.001$), and TAC + 5-FU at 3 months ($p=0.030$).

The 12-month difference between Nd:YAG laser + TAC and TAC + 5-FU did not reach statistical significance ($p=0.097$). No serious adverse events were observed during the study period.

Table 2: Treatment characteristics.

Treatment characteristic	TAC monotherapy (n=13)	TAC + 5-FU (n=13)	Nd:YAG laser + TAC (n=26)
Mean number of treatment sessions	12.2	10.6	7.2
Treatment interval	Every 2 weeks	Every 2 weeks	Every 2 weeks
TAC dose	4 mg/cm²	4 mg/cm²	4 mg/cm²
5-FU dose	Not applicable	10 mg/cm²	Not applicable
Laser wavelength	Not applicable	Not applicable	1064 nm
Pulse duration	Not applicable	Not applicable	0.33 ms
Fluence	Not applicable	Not applicable	4.4 J/cm²
Repetition rate	Not applicable	Not applicable	6-8 Hz
Temperature endpoint	Not applicable	Not applicable	48°C

Table 3: Patient POSAS outcomes.

Time point/ analysis	TAC monotherapy	TAC + 5-FU	Nd:YAG laser + TAC	Overall ANOVA (p value)	Significant LSD post-hoc comparisons
Baseline	36.69±4.37 (n=13)	37.69±3.99 (n=13)	38.62±5.49 (n=26)	0.508	None
3 months, including progressive cases	26.00±4.83 (n=13)	22.69±3.54 (n=13)	19.35±7.36 (n=26)	0.007	Laser + TAC versus TAC: p=0.002
12 months, including progressive cases	30.08±9.48 (n=13)	24.92±8.42 (n=13)	20.65±10.19 (n=26)	0.020	Laser + TAC versus TAC: p=0.006
3 months, excluding progressive cases	26.00±4.83 (n=13)	22.69±3.54 (n=13)	18.40±5.68 (n=25)	<0.001	Laser + TAC versus TAC: p<0.001; Laser + TAC versus TAC + 5-FU: p=0.016
12 months, excluding progressive cases	25.50±4.12 (n=10)	21.64±2.66 (n=11)	17.30±3.88 (n=23)	<0.001	Laser + TAC versus TAC: p<0.001; Laser + TAC versus TAC + 5-FU: p=0.003; TAC versus TAC + 5-FU: p=0.021

Values are shown as mean±standard deviation. Lower POSAS scores indicate better outcomes.

Table 4: Observer POSAS outcomes.

Time point	TAC monotherapy	TAC + 5-FU	Nd:YAG laser + TAC	Overall ANOVA (p value)	Significant LSD post-hoc comparisons
Baseline	39.38±4.05 (n=13)	40.38±3.23 (n=13)	41.50±4.16 (n=26)	0.278	None
3 months	22.08±4.19 (n=13)	21.54±2.54 (n=13)	17.92±5.75 (n=26)	0.018	Laser + TAC versus TAC: p=0.014; Laser + TAC versus TAC + 5-FU: p=0.030
12 months	28.15±9.19 (n=13)	22.69±7.47 (n=13)	17.81±8.63 (n=26)	0.003	Laser + TAC versus TAC: p=0.001

Values are shown as mean±standard deviation. Lower POSAS scores indicate better outcomes.

DISCUSSION

Mechanisms of therapeutic efficacy

The short-pulsed Nd:YAG laser penetrates to the reticular dermis (2-3 mm), where pathological scarring occurs.[7]

Genesis-mode (0.33 ms, 4.4 J/cm²) creates controlled thermal zones for gradual deep tissue heating, minimizing epidermal damage and targeting deeper collagen and blood vessels.[8]

Temperature-controlled collagen remodeling

Target temperature of 48°C induces heat shock protein activation in fibroblasts, upregulating type I procollagen synthesis for tissue remodeling. This avoids denaturation threshold (~60°C) and irreversible collagen damage.[9] 8-10s exposure at 45°C is optimal for collagen type I synthesis, while 60°C risks cell damage.[8,9] In contrast, surface temperature is generally lower than that of the deeper layers. Collagen denaturation is considered desirable when treating keloids. Gradual heating with short

pulses preserves the epidermis while selectively affecting the reticular dermis, disrupting pathological collagen architecture and stimulating organized synthesis.[9]

Synergistic combination therapy

Laser-induced thermal effects reduce vascularization through selective vessel thermolysis; triamcinolone inhibits fibroblast proliferation and collagen/glycosaminoglycan synthesis, and promotes collagen degradation. Immediate steroid injection post-laser maximizes drug penetration in thermally altered matrix.[10]

Vascular targeting and inflammatory modulation

1064 nm laser targets hemoglobin chromophores in dilated capillaries and feeding vessels, coagulating them to interrupt inflammatory cascades.[11] Triamcinolone injection exploits vascular disruption for increased local delivery.

Comparison with combination therapies

The Nd:YAG laser + TAC combination demonstrated superior outcomes compared with TAC monotherapy, but no statistically significant long-term advantage over TAC + 5-FU. 5-FU acts as an antimetabolite, inhibiting DNA synthesis and cell proliferation of rapidly dividing fibroblasts.[12]

Meta-analyses and recent evidence-based reviews confirm that 5-FU plus TAC can achieve faster improvement in vascularity, height reduction, and symptom relief with fewer side effects than TAC monotherapy.[13,14] A recent study of postoperative keloid management also reported that Nd:YAG laser treatment combined with intralesional TAC was more effective than TAC injection alone at 12 months.[15] Adding 5-FU to the laser-TAC regimen may yield additive benefits through multi-pathway targeting and should be evaluated prospectively.

Technical innovation and standardization

Infrared temperature monitoring

Real-time IR camera monitoring enables standardized temperature endpoints across patients/scar types, prevents overheating, and ensures therapeutic doses.[9]

Adaptive treatment parameters

Spot size selection based on scar thickness optimizes thermal penetration and surface control.

Pain management and tolerance

Treatment at 48°C induces moderate pain due to nociceptor activation. Immediate cold air cooling (Zimmer Cryo 6) provides heat dissipation and desensitization, crucial for compliance over multiple sessions.[7]

Limitations and clinical implications

Limitations include open-label, non-blinded design and lack of histologic endpoints. Sample size restricted subgroup analysis (keloid versus hypertrophic scar, Fitzpatrick types). Follow-up limited to 12 months; data on long-term recurrence needed.

The efficiency of combination therapy (7.2 versus 10.6-12.2 sessions) improves compliance and reduces healthcare burden. Prospective evaluation of triplet therapy (laser + triamcinolone + 5-FU) and temperature target optimization (45°C versus 48°C versus 55°C) is warranted.

Long-term studies and biomarker-based stratification are needed for personalized treatment and mechanistic understanding.

AI-driven infrared monitoring may enable further standardization and operator-independent dose control.

CONCLUSION

Combining short-pulsed 1064 nm Nd:YAG laser therapy with intralesional triamcinolone injection provides superior and more rapid improvement for hypertrophic scars and keloids compared to steroid monotherapy, with potential equivalence to established 5-FU/TAC regimens. The incorporated temperature monitoring and spot size adaptation ensure standardized, safe, and reproducible clinical outcomes.

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Ethical approval: The study was approved by the Ethics Committee of the North Rhine Medical Association, Düsseldorf, Germany, File No.: 2025207

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