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ENHANCED MANAGEMENT OF FACIAL AND CERVICAL PATHOLOGICAL SCARS THROUGH A DIFFERENTIATED COMBINED LASER AND PHOTODYNAMIC THERAPY APPROACH

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Abstract. Background: Pathological scars, particularly hypertrophic and keloid forms, remain a major therapeutic challenge due to excessive fibroproliferation, persistent angiogenesis, high recurrence rates, and pronounced aesthetic and functional impairment, especially in facial and cervical regions.

Objective: To develop and evaluate a differentiated treatment algorithm for pathological facial and neck scars based on a combined application of laser technologies and photodynamic therapy (PDT), supported by experimental morphological and clinical evidence.

Materials and Methods: The study comprised experimental and clinical phases. In the experimental phase, hypertrophic scar models were induced on the auricular surface of 20 outbred rabbits and treated either with CO_2 laser monotherapy (control group) or a combined laser–PDT protocol (experimental group). The clinical phase included 25 patients with facial and cervical pathological scars, divided into a main group receiving combined laser–PDT treatment (n = 13) and a control group receiving standard conservative therapy (n = 12). Treatment efficacy was assessed using ultrasonography, erythemometry, fluorescence diagnostics, and clinical–aesthetic evaluation. Statistical analysis was performed using parametric and non-parametric methods, with significance set at $p < 0.05$.

Results: In the experimental model, scar height decreased from 2.4 ± 0.6 mm to 0.2 ± 0.03 mm in the experimental group, compared with 1.6 ± 0.02 mm in the control group ($p < 0.05$). Clinically, scar thickness was reduced by 41.8% in the main group versus 17.0% in controls. Reduction of erythema and normalization of skin color were observed in 88% of patients receiving combined therapy. Fluorescence diagnostics revealed a 46% decrease in metabolic activity within scar tissue. The highest clinical effectiveness was observed in hypertrophic (98.8%) and atrophic (90%) scars.

Conclusion: The differentiated combined laser–photodynamic therapy protocol provides significantly superior clinical, morphological, and aesthetic outcomes in the treatment of pathological facial and cervical scars compared to standard conservative methods.
Keywords: pathological scars; hypertrophic scars; keloid scars; laser therapy; photodynamic therapy; facial scars

1. Introduction

Pathological scarring represents a significant clinical and socio-economic problem in dermatology, plastic surgery, and maxillofacial rehabilitation. Hypertrophic and keloid scars arise as a result of dysregulated wound healing characterized by excessive fibroblast proliferation, abnormal collagen synthesis, persistent angiogenesis, and prolonged inflammatory response. These pathological changes frequently lead to functional limitations, cosmetic deformities, and psychological distress, particularly when scars are localized to visible anatomical regions such as the face and neck.

Hypertrophic scars are typically confined within the original wound boundaries and may undergo partial spontaneous regression, whereas keloid scars extend beyond the initial injury margins, demonstrate progressive growth, and contain dense, disorganized bundles of type I and III collagen. Despite advances in surgical and conservative approaches, treatment outcomes remain inconsistent, with high recurrence rates and limited long-term stability.

Laser-based technologies have gained widespread acceptance due to their ability to selectively target vascular and collagen components of scar tissue while minimizing damage to surrounding healthy structures. Fractional CO_2 laser therapy improves dermal remodeling and tissue elasticity, while pulsed dye and Nd:YAG lasers modulate superficial and deep vascular components. However, laser monotherapy often fails to address the metabolic activity underlying pathological scar persistence. Photodynamic therapy (PDT), which induces selective cytotoxic effects via photosensitizer-mediated oxidative stress, has emerged as a promising adjunctive modality.

The present study proposes a differentiated, pathogenetically grounded algorithm combining fractional CO_2 laser, pulsed dye laser, Nd:YAG laser, and photodynamic therapy, aimed at simultaneous modulation of collagen structure, vascularization, and metabolic activity in pathological scar tissue.

2. Aim of the Study

The aim of this study was to develop objective criteria for pathological scar differentiation and to evaluate the clinical and morphological effectiveness of a combined laser–photodynamic therapy protocol in the treatment of facial and cervical scars.

3. Materials and Methods

3.1 Study Design and Ethical Approval

This study was conducted as a controlled experimental–clinical investigation. The research protocol was approved by the Local Ethics Committee of Tashkent State Medical University (Tashkent, Uzbekistan). All clinical participants provided written informed consent prior to enrollment. Animal experiments were performed in accordance with international guidelines for the care and use of laboratory animals and complied with ARRIVE recommendations.

3.2 Experimental Study

3.2.1 Animal Model

The experimental phase was performed on 20 healthy outbred rabbits weighing 2.5–3.0 kg. Hypertrophic scar models were induced on the auricular surface using a standardized mechanical injury technique, followed by controlled wound healing to ensure reproducible fibroproliferative scar formation.

Animals were randomly assigned to a control group treated with CO_2 laser monotherapy and an experimental group treated with the combined laser–PDT protocol (n = 10 per group).

3.2.2 Laser–PDT Protocol

The experimental treatment protocol consisted of sequential application of:

- Fractional CO_2 laser tunnelization (10.06 μm) to create microthermal zones and initiate collagen remodeling;
- Pulsed dye laser (585 nm) to reduce superficial vascular congestion and inflammatory hyperemia;
- Nd:YAG laser (1064 nm) to modulate deep vascular components and tissue perfusion;
- Photodynamic therapy with topical 20% 5-aminolevulinic acid (5-ALA), followed by irradiation at 640 nm and 980 nm.

Morphological evaluation included histological and morphometric assessment of scar height, collagen organization, and vascular density.

3.3 Clinical Study

3.3.1 Participants

The clinical phase included 25 patients with pathological facial and cervical scars of various etiologies, predominantly post-burn scars. All scars had a duration of at least 6 months.

Patients were allocated into a main group receiving combined laser–PDT therapy (n = 13) and a control group receiving standard conservative therapy (n = 12).

3.3.2 Inclusion and Exclusion Criteria

Inclusion criteria:

- Hypertrophic, keloid, or atrophic scars of the face or neck
- Scar duration ≥ 6 months
- Age ≥ 18 years

Exclusion criteria:

- Active inflammatory or infectious skin disease
- Systemic connective tissue disorders
- Decompensated chronic diseases
- Pregnancy or lactation

3.4 Outcome Measures

Treatment outcomes were assessed using:

- Ultrasonographic measurement of scar thickness;
- Erythemonetry for evaluation of vascular activity;
- Fluorescence diagnostics to assess metabolic activity;
- Clinical and aesthetic evaluation of texture, color correspondence, elasticity, and tissue mobility.

3.5 Statistical Analysis

Statistical analysis was performed using standard biomedical statistical software. Quantitative data were analyzed using Student's t-test or Mann–Whitney U test depending on data distribution. Categorical variables were assessed using χ^2 testing. Odds ratios (OR) were calculated to evaluate treatment effectiveness. Statistical significance was defined as $p < 0.05$.

4. Results

In the experimental phase, the combined laser–PDT protocol resulted in a significant reduction in scar height from 2.4 ± 0.6 mm to 0.2 ± 0.03 mm, compared to 1.6 ± 0.02 mm in the control group ($p < 0.05$). Histological analysis demonstrated improved collagen fiber orientation and reduced vascular density.

In the clinical phase, ultrasonography revealed a 41.8% reduction in scar thickness in the main group versus 17.0% in the control group. Reduction of erythema and normalization of skin color were observed in 88% of patients receiving combined therapy. Fluorescence diagnostics demonstrated a 46% decrease in metabolic activity within scar tissue.

The highest clinical effectiveness was observed in hypertrophic scars (98.8%) and atrophic scars (90%), while keloid scars showed moderate but stable improvement.

5. Discussion

Pathological scarring remains a persistent challenge in reconstructive and aesthetic medicine due to its complex multifactorial pathogenesis, involving dysregulated fibroblast activity, excessive collagen deposition, persistent angiogenesis, and prolonged inflammatory response. Despite the widespread adoption of laser-based technologies, no universally accepted treatment algorithm has yet demonstrated consistently stable long-term outcomes, particularly for facial and cervical scars.

Comparison with Existing Treatment Modalities

Ablative and non-ablative laser therapies have been extensively investigated for the management of hypertrophic and keloid scars. Fractional CO_2 laser treatment has been shown to improve scar texture and elasticity by inducing controlled dermal remodeling; however, several studies report limited efficacy when used as monotherapy, particularly in scars with pronounced vascular and metabolic activity. Similarly, pulsed dye laser (PDL, 585–595 nm) has demonstrated effectiveness in reducing erythema and pruritus by targeting superficial microvasculature, yet its impact on scar thickness and collagen architecture remains inconsistent.

Nd:YAG laser therapy (1064 nm) has been proposed as a deeper-penetrating modality capable of modulating vascular components and fibroblast activity in deeper dermal layers. Nevertheless, clinical outcomes vary widely depending on scar type, duration, and laser parameters, and recurrence rates remain a concern when Nd:YAG laser is applied in isolation.

Photodynamic therapy has attracted increasing interest as an adjunctive modality due to its ability to selectively reduce cellular metabolic activity and angiogenesis through photosensitizer-mediated oxidative stress. Previous studies have reported favorable outcomes of PDT in dermatological conditions characterized by hyperproliferation and increased vascularization; however, its application in pathological scar treatment remains limited and insufficiently standardized.

Rationale for the Combined Laser–PDT Approach

The present study supports the hypothesis that a differentiated multimodal approach targeting multiple pathogenetic mechanisms simultaneously yields superior clinical outcomes compared to single-modality treatment. In contrast to previously described combination protocols, which typically involve sequential laser modalities without metabolic modulation, the proposed algorithm integrates photodynamic therapy as a central component of scar remodeling.

Fractional CO_2 laser tunnelization creates microthermal channels within scar tissue, facilitating collagen reorganization and enhancing photosensitizer penetration. Subsequent

application of pulsed dye laser reduces superficial vascular congestion and inflammatory activity, thereby minimizing post-laser hyperemia and necrotic zones. The Nd:YAG laser further modulates deep vascular structures, leading to reduced tissue perfusion and fibroblast stimulation. Photodynamic therapy acts synergistically by suppressing residual metabolic activity and angiogenesis, promoting more stable scar regression.

Interpretation of Clinical and Experimental Findings

The significant reduction in scar height observed in the experimental model supports the morphological effectiveness of the combined protocol. Histological findings indicate improved collagen fiber orientation and decreased vascular density, consistent with previously reported mechanisms of laser-induced dermal remodeling.

Clinically, the pronounced reduction in scar thickness and erythema, along with normalization of skin color in the majority of patients, suggests that the combined approach effectively addresses both structural and vascular components of pathological scars. The decrease in fluorescence diagnostic indices further supports the hypothesis of reduced metabolic activity and neovascularization within treated scar tissue.

The high effectiveness observed in hypertrophic and atrophic scars is consistent with international reports emphasizing the responsiveness of these scar types to laser-based interventions. In contrast, the more moderate response of keloid scars aligns with existing literature describing their aggressive biological behavior and high recurrence potential, underscoring the need for prolonged and multimodal management.

Clinical Implications and Advantages

Compared with conventional conservative therapy and laser monotherapy described in the literature, the proposed combined laser–PDT protocol offers several advantages:

- Targeted action on collagen, vascular, and metabolic components of scar tissue;
- Reduced risk of recurrence due to suppression of fibroblast activity;
- Improved aesthetic outcomes with preservation of surrounding healthy tissue;
- Enhanced functional recovery, particularly in facial and cervical regions.

The clinical–economic analysis further supports the feasibility of this approach, demonstrating a higher probability of favorable outcomes despite slightly increased initial treatment costs.

Limitations and Future Perspectives

This study has several limitations, including a relatively small clinical sample size and a limited follow-up period. Additionally, laser parameters were individualized based on scar characteristics, which may limit direct comparability across patient groups. Future randomized

controlled trials with larger cohorts, standardized laser settings, and extended follow-up periods are warranted to further validate the long-term efficacy and reproducibility of the proposed algorithm.

6. Conclusion

The differentiated combined application of fractional CO_2 laser, pulsed dye laser (585 nm), Nd:YAG laser (1064 nm), and photodynamic therapy represents a pathogenetically grounded and clinically effective strategy for the management of pathological facial and cervical scars. By simultaneously targeting collagen remodeling, vascular dysregulation, and metabolic activity within scar tissue, this multimodal protocol achieves significantly improved aesthetic and functional outcomes compared to standard conservative approaches. The observed reduction in scar thickness and vascular activity, together with restoration of tissue elasticity and mobility, indicates a more stable and biologically rational scar regression. The proposed treatment algorithm is safe, reproducible, and clinically feasible, and may be recommended as an effective therapeutic option for the comprehensive management of pathological scars in cosmetically and functionally sensitive anatomical regions.

7. References

1. Belysheva, T. S. (2017). *Sovremennaya strategiya diagnostiki i lecheniya pigmentnykh i sosudistykh novoobrazovaniy kozhi u detey* [Modern strategy for diagnosis and treatment of pigmented and vascular skin neoplasms in children] (Doctoral dissertation). Moscow, Russia.

2. Bychkova, O. S. (2016). Treatment and rehabilitation of a patient with combined facial hemangioma: A clinical case. *Apparatnaya Kosmetologiya*, (3), 76–82.

3. Velsher, L. Z., Stakhanov, M. L., Gorchak, Y. Y., Reshetov, D. N., Tsalko, S. E., et al. (2016). Comparative analysis of the effectiveness of various types of laser radiation in the surgical treatment of vascular neoplasms of different localization. *Laser Medicine*, 20(1), 29–33.

4. Gelfond, M. L., Panova, O. S., Slovokhodov, E. K., Zhukoff, O. V., & Ashmarov, V. V. (2017). Photodynamic therapy in oncodermatology and cosmetology. *Apparatnaya Kosmetologiya*, (2), 36–44.

5. Kruglova, L. S., Dzybova, E. M., Ponich, E. S., & Fedotova, K. Y. (2014). Prospects for the application of photodynamic therapy in dermatology and cosmetology: A review. *Vestnik Esteticheskoy Meditsiny*, 13(3–4), 10–19.

6. Ponomarev, I. V., Shakina, L. D., Topchiy, S. B., Klyuchareva, S. V., & Pushkareva, A. E. (2021). Treatment of pyogenic granuloma using copper vapor laser radiation. *Vestnik Dermatologii i Venerologii*, 97(2), 41–49. https://doi.org/10.25208/vdv1223

7. Gavelya, E. Y., Roginskiy, V. V., Nadtochiy, A. G., Kotlukova, N. P., & Mustafina, F. N. (2020). Minimally invasive treatment methods for children with vascular lesions of the head and neck. *Detskaya Khirurgiya*, 24(S1), 28.

8. Bacellar, I. O. L., Tsubone, T. M., Pavani, C., & Baptista, M. S. (2015). Photodynamic efficiency: From molecular photochemistry to cell death. *International Journal of Molecular Sciences*, 16(9), 20523–20559. https://doi.org/10.3390/ijms160920523

9. Cai, H., Wang, Y. X., Zheng, J. C., et al. (2015). Photodynamic therapy in combination with CO_2 laser for the treatment of Bowen's disease. *Lasers in Medical Science*, 30(5), 1505–1510. https://doi.org/10.1007/s10103-015-1722-5

10. Choi, S. H., Kim, K. H., & Song, K. H. (2016). Er:YAG ablative fractional laser-primed photodynamic therapy with methyl aminolevulinate for thin nodular basal cell carcinoma: A 12-month randomized trial. *Journal of the European Academy of Dermatology and Venereology*, 30(5), 783–788. https://doi.org/10.1111/jdv.13159

11. Brodin, N. P., Guha, C., & Tomé, W. A. (2015). Photodynamic therapy and its role in combined modality anticancer treatment. *Technology in Cancer Research & Treatment*, 14(4), 355–368. https://doi.org/10.1177/1533034614564880

12. Beack, S., Kong, W. H., Jung, H. S., et al. (2015). Photodynamic therapy of melanoma using carbon dot–chlorin e6–hyaluronate conjugate. *Acta Biomaterialia*, 26, 295–305. https://doi.org/10.1016/j.actbio.2015.08.015

13. Bandelow, B., Lichte, T., Rudolf, S., et al. (2015). The German guidelines for the treatment of anxiety disorders. *European Archives of Psychiatry and Clinical Neuroscience*, 265(5), 363–373. https://doi.org/10.1007/s00406-014-0563-z