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Original Article

Clinical characteristics of patients receiving fractional laser therapy for facial scars and their association with the duration of postoperative erythema

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Abstract: Objectives: To investigate the clinical characteristics of patients with post-traumatic facial hypertrophic scars treated with fractional carbon dioxide (CO_2) laser therapy and to identify factors associated with the duration of postoperative erythema. Methods: This retrospective study included 106 patients who underwent fractional CO_2 laser therapy for post-traumatic facial hypertrophic scars at Huzhou Maternity & Child Health Care Hospital between January and April 2025. Demographic data, scar characteristics (area, location, Vancouver Scar Scale [VSS] score), laser parameters, adverse reactions, and erythema duration were collected. Patients were categorized into short-duration and long-duration erythema groups using a 14-day cutoff. Clinical variables were compared between groups, and those with $P < 0.05$ were further analyzed using Spearman correlation. Results: Among 106 included patients, most were children or adolescents. The median erythema duration was 11 days, and 25 patients experienced erythema lasting longer than 14 days. Patients in the long-duration group had significantly higher age, scar area, VSS score, and laser energy compared with those in the short-duration group ($P < 0.05$). All four variables showed a positive correlation with erythema duration ($P < 0.0001$). Analysis of adverse events revealed a significant difference in Fitzpatrick skin type distribution between patients with and without edema ($P = 0.021$). Conclusions: The duration of postoperative erythema is strongly associated with patient age, scar severity, and laser treatment parameters. Preoperative evaluation should account for these factors to guide individualized treatment planning and postoperative care, thereby minimizing the risk of prolonged erythema.

Keywords: Clinical characteristics, hypertrophic scar, fractional carbon dioxide laser, postoperative erythema

Introduction

Hypertrophic scars represent a pathological overgrowth of fibrous tissue resulting from an imbalance between collagen synthesis and degradation during the wound-healing process. They are typically characterized by raised, erythematous, and firm lesions, often accompanied by pruritus or pain [1]. The face, as a highly visible and expressive area, is particularly prone to trauma. The development of hypertrophic scars in this region can adversely affect both physical appearance and psychological well-being, especially in children and adolescents [2-4]. It has been reported that approximately 5%-10% of patients with traumatic skin injuries develop hypertrophic scars, with a higher incidence among Asians than Caucasians [1, 4, 5]. Therefore, early intervention for facial hypertrophic scars carries substantial clinical importance.

In recent years, fractional carbon dioxide (CO_2) laser therapy has emerged as a key modality for the treatment of various types, particularly hypertrophic scars [1]. As an ablative technique, the fractional CO_2 laser generates numerous microthermal zones on the skin surface, inducing a localized inflammatory response, stimulating fibroblast activation, and promoting collagen and elastin fiber regeneration and remodeling. These mechanisms collectively contribute to scar softening, reduction in thickness, and improvement in texture and pigmentation [6, 7]. Previous studies have demonstrated that fractional CO_2 laser therapy can significantly improve both subjective symptoms and objective assessment scores of scars, enhance skin

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elasticity, and restore normal pigmentation patterns. Moreover, initiating treatment during the early phase of scar formation has been associated with superior therapeutic outcomes [7].

However, as an ablative procedure, fractional laser therapy is also associated with a variety of adverse effects and complications [8]. Among these, erythema is the most common and prominent post-treatment reaction, typically occurring immediately after the procedure. It manifests as noticeable redness or flushing and is primarily attributed to localized vasodilation, superficial inflammation, and vascular remodeling [1, 9]. Clinically, the duration of erythema varies substantially among individuals: some patients recover within a few days, whereas others experience persistent erythema lasting for several weeks or, in rare cases, more than three months [9-11]. Previous studies have indicated that the duration of post-treatment erythema is influenced by multiple factors, including laser energy settings, scar type and thickness, Fitzpatrick skin type, treatment area, and the degree of inflammatory response [6, 11, 12]. Prolonged erythema not only delays wound recovery but also increases the risk of post-inflammatory hyperpigmentation (PIH), thereby adversely affecting patient satisfaction and perceived treatment outcomes [8, 9, 11, 13, 14]. Nevertheless, studies specifically investigating the duration and clinical predictors of erythema following fractional CO_2 laser therapy remain limited.

Therefore, this study aimed to retrospectively analyze the demographic characteristics, scar features, and laser treatment parameters of patients with post-traumatic facial scars treated with fractional CO_2 laser therapy, in order to elucidate their clinical profiles and identify factors associated with the duration of postoperative erythema. The ultimate objective was to identify high-risk populations and predictive indicators, thereby providing evidence to guide individualized treatment planning and postoperative management, and ultimately enhance the safety and controllability of scar treatment.

Methods

Study design

This retrospective observational study included 106 patients who underwent fractional CO_2 laser therapy for post-traumatic facial hypertrophic scars at Huzhou Maternity & Child Health Care Hospital between January and April 2025. Based on the duration of postoperative erythema, patients were categorized into a short-duration group (n = 81) and a long-duration group (n = 25).

Inclusion criteria: (1) clearly documented post-traumatic facial hypertrophic scars resulting from mechanical lacerations; (2) complete treatment records, including at least one session of fractional CO_2 laser therapy with detailed treatment parameters and postoperative observations; (3) presence of post-treatment erythema; (4) availability of continuous follow-up data regarding the duration of erythema; and (5) no age restriction. Exclusion criteria: (1) unclear etiology of the scar; (2) incomplete baseline information, treatment documentation, or follow-up data; (3) presence of active dermatologic diseases such as eczema or psoriasis; and (4) diagnosis of immunologic disorders. This study was approved by the Ethics Committee of Huzhou Maternity & Child Health Care Hospital (Approval NO. 2025-J-036).

Fractional laser treatment

Before treatment, each scar was assessed by a physician for type, area, morphology, and Fitzpatrick skin type to determine individualized treatment parameters. The treatment area was then cleansed, and a topical anesthetic cream (Compound Lidocaine Cream; Tongfang Pharmaceutical Group Co., Ltd., China) was applied under occlusion for 30-60 minutes to achieve adequate surface anesthesia. After removal of the dressing, the area was cleansed again with sterile normal saline.

All procedures were performed using the JLT-100C fractional CO_2 laser system (Hubei Jin Lai Te Technology Co., Ltd., China). The ablative fractional scanning mode was applied, with a typical spot diameter ranging from 120 to 300 μm. Treatment energy was individualized according to each patient's condition, generally between 15 and 25 mJ. The scanning density was set between 5% and 15%, with either random or linear scanning patterns. Parameters were dynamically adjusted intraoperatively based on real-time skin responses until the desired endpoint - a uniform grid pattern - was achieved.

After treatment, a cold compress was applied for 15-20 minutes to relieve the thermal sensation and reduce early inflammation. Patients were instructed to cleanse the treated area daily with saline, avoid hot water and mechanical friction, and apply recombinant human epidermal growth factor gel (Guilin Huanuowei Gene Pharmaceutical Co., Ltd., China) three times daily before crust formation to maintain a moist wound environment. For patients undergoing multiple treatment sessions, the interval between sessions was typically 4-6 weeks, as determined by the attending physician based on clinical improvement. Follow-up began after the final treatment session, and all patients were monitored for at least six weeks postoperatively.

Data extraction

All data were retrospectively extracted from the hospital's electronic medical record system by two independent investigators. The collected variables included sex, age, Fitzpatrick skin type, educational level, scar type, scar area, scar location, Vancouver Scar Scale (VSS) score, laser energy, number of treatment sessions, duration of erythema, and adverse reactions (edema, pain, and PIH).

Laser energy was defined as the highest energy level applied during any single treatment session for each patient, serving as an indicator of the peak thermal effect on local tissue. For younger children, the Fitzpatrick skin type was determined through a combination of caregiver reporting and physician assessment.

The duration of erythema was defined as the number of days from the final laser treatment to the complete resolution of erythema at the treated site. Based on previous studies, erythema lasting longer than 14 days was considered prolonged [1, 15-17].

Statistical analysis

All statistical analyses were conducted using SPSS version 26.0 (IBM Corp., Armonk, NY, USA). Continuous variables were assessed for normality and presented as mean ± standard deviation or median with interquartile range, as appropriate. Categorical variables were expressed as frequencies and percentages.

Univariate comparisons between the short- and long-duration erythema groups were performed using independent-samples *t*-tests or Mann-Whitney *U* tests for continuous variables, depending on data distribution. Categorical variables were compared using the chi-squared test or Fisher's exact test, depending on sample size and distribution. Variables with $P < 0.05$ in the univariate analysis were further evaluated using Spearman correlation to explore associations between continuous variables. All statistical tests were two-tailed, and a P value < 0.05 was considered statistically significant.

As this was a retrospective study, the sample size was determined by the number of eligible patients. To assess the adequacy of the sample size, a sensitivity power analysis was performed using G*Power version 3.1.9.7 (two-sided $\alpha = 0.05$, N = 106). The analysis indicated that the minimal detectable correlation coefficient at 80% power was $|r| = 0.27$. All observed correlations with erythema duration exceeded this threshold, corresponding to a statistical power greater than 0.80.

Results

Baseline characteristics and treatment parameters

The demographic and treatment-related characteristics of the included patients are summarized in **Table 1**. The cohort consisted predominantly of children, with most patients aged ≤12 years and a balanced sex distribution. Scars were primarily located on the forehead and eyelid. Fitzpatrick skin type III was the most common, and the scar area and VSS scores indicated that most lesions were of moderate severity. Regarding treatment parameters, the majority of patients underwent fractional CO_2 laser therapy at moderate energy levels, and two to three treatment sessions were most frequently administered.

Educational level, lifestyle factors, and comorbidities in adult patients

Table 2 and **Figure 1** summarize the distribution of educational attainment, lifestyle factors

Table 1. Baseline characteristics and treatment parameters of all patients (n [%], M [Q1, Q3])

Variable Category	Value
Sex	
Male	52 (49.1)
Female	54 (50.9)
Age (years)	
≤ 12	84 (79.2)
> 12- < 18	6 (5.7)
≥ 18	16 (15.1)
Fitzpatrick skin type	
I	3 (2.8)
II	34 (32.1)
III	58 (54.7)
IV	11 (10.4)
Scar area (cm^2)	
< 3	21 (19.8)
3-5	76 (71.7)
> 5	9 (8.5)
VSS score	6 (5, 6)
Scar location	
Upper eyelid/Periorbital area	31 (29.2)
Nasal area	5 (4.7)
Forehead/Frontal area	35 (33.0)
Eyebrow/Supraorbital ridge	8 (7.5)
Perioral area	7 (6.6)
Cheek/Zygomatic area	7 (6.6)
Mandibular/Submandibular area	13 (12.3)
Laser energy (mJ)	20 (16, 22)
No. of sessions	3 (2, 3)

VSS: Vancouver Scar Scale.

(smoking and alcohol consumption), and comorbidities among adult patients aged ≥ 18 years. Educational levels were primarily distributed among senior high school and college or above, with a small proportion of individuals still enrolled in school. A subset of adult patients reported smoking or alcohol use, and hypertension and diabetes were the most prevalent comorbidities. These findings provide background information on the general health status of the adult subgroup, serving as a reference for subsequent comparative analyses.

Adverse events in all patients

Table 3 presents the overall incidence of adverse events following treatment, including

Table 2. Educational level, lifestyle factors, and comorbidities of adult patients (n [%], M [Q1, Q3])

Variable Category	Value
Educational level	
Junior high school	3 (18.8)
Senior high school	7 (43.8)
College/University	6 (37.5)
Smoking status	
Yes	8 (50.0)
No	8 (50.0)
Alcohol consumption	
Yes	7 (43.8)
No	9 (56.3)
Comorbidities	
Diabetes mellitus	3 (18.8)
Hypertension	2 (12.5)

erythema, localized edema, and PIH. Erythema was universally observed as a normal post-treatment reaction, with a median duration of 11 days. Both edema and PIH occurred relatively frequently. The overall incidence of adverse events remained within acceptable limits, indicating that this treatment approach was generally safe for the study population.

Comparison of baseline and treatment characteristics by erythema duration

Table 4 compares the baseline characteristics and treatment parameters between the short- and long-duration erythema groups, encompassing both pediatric and adult patients. Among the 106 included patients, 25 experienced erythema lasting longer than two weeks. Patients with prolonged erythema were significantly older and had larger scar areas, higher VSS scores, and higher laser energy levels compared with those with shorter erythema duration ($P = 0.002$, $P < 0.001$, $P < 0.001$, and $P < 0.001$, respectively). These findings suggest that older age, greater scar extent and severity, and higher treatment energy are associated with an increased likelihood of prolonged erythema. No significant differences were observed between the two groups regarding sex, Fitzpatrick skin type, scar location, or number of treatment sessions (all $P > 0.05$), indicating that these factors may be less relevant to erythema duration.

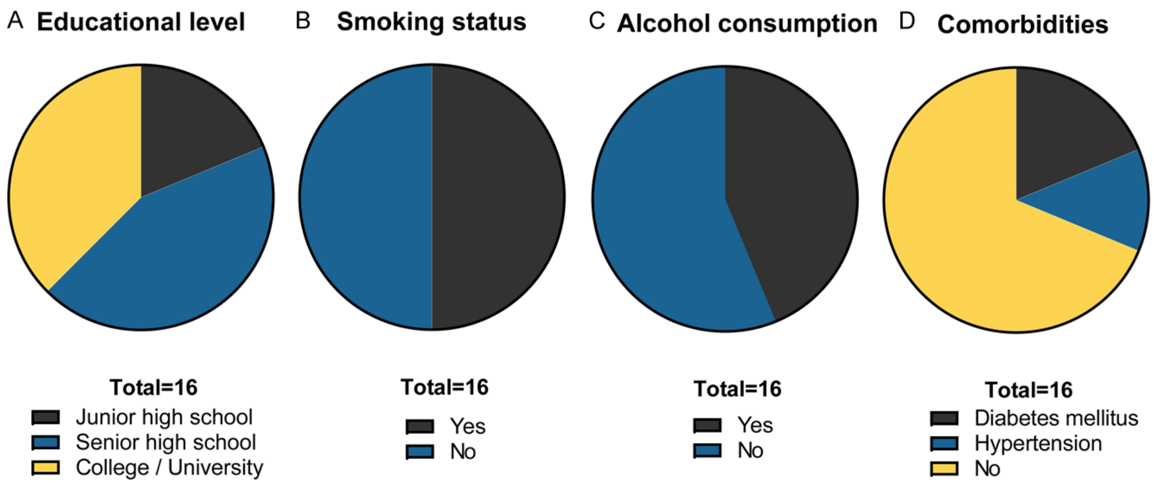

Figure 1. Educational level, lifestyle factors, and comorbidities of adult patients. A. Educational level of adult patients; B. Smoking status of adult patients; C. Alcohol consumption of adult patients; D. Comorbidities of adult patients.

Table 3. Adverse reactions after fractional CO_2 laser treatment in all patients (n [%], M [Q1, Q3])

Variable Category	Value
Duration of erythema (days)	11 (8, 14)
PIH	
Yes	46 (43.4)
No	60 (56.6)
Edema	
Yes	39 (36.8)
No	67 (63.2)

CO_2: Carbon dioxide; PIH: Post-inflammatory hyperpigmentation.

Correlation between erythema duration and baseline/treatment variables

Figure 2 shows the Spearman correlation analysis between erythema duration and the four variables that were significantly different in the univariate analysis (**Table 4**): age, scar area, VSS score, and laser energy. All four variables exhibited positive correlations with erythema duration, with the strongest correlation observed for the VSS score, followed by laser energy (all $P < 0.0001$). These findings indicate that greater scar severity and higher treatment intensity are associated with longer erythema duration, consistent with the results of the group comparisons.

Comparison of social and health factors by erythema duration in adult patients

Table 5 compares educational level, lifestyle behaviors, and comorbidities between short- and long-duration erythema groups among adult patients. No significant differences were observed in educational level, smoking status, alcohol consumption, or comorbidities between the two groups (all $P > 0.05$), suggesting that these social and health-related factors were not major predictors of erythema duration in adults.

Impact of scar location and Fitzpatrick skin type on postoperative complications

Table 6 summarizes the association between scar anatomical location and Fitzpatrick skin type with the occurrence of edema and PIH. Although patients with scars located in the eyelid and forehead/frontal regions exhibited higher rates of edema, these differences did not reach statistical significance ($P > 0.05$). Similarly, PIH occurred more frequently in patients with Fitzpatrick skin types III and IV, but the group differences were not statistically significant ($P > 0.05$). However, a significant difference in the distribution of Fitzpatrick skin types was observed between patients with and without edema ($P = 0.021$), suggesting that skin phototype may influence the risk of developing postoperative edema.

Table 4. Comparison of baseline and treatment characteristics between short- and long-duration erythema groups in all patients (n [%], M [Q1, Q3])

Variable	Short-duration group (n = 81)	Long-duration group (n = 25)	Statistic	*P* value
Sex			0.63	0.427
Male	38 (46.9)	14 (56.0)		
Female	43 (53.1)	11 (44.0)		
Age (years)	5 (2, 9)	9 (6, 30)	-3.06	0.002
Fitzpatrick skin type			-	0.906
I	2 (2.5)	1 (4.0)		
II	26 (32.1)	8 (32.0)		
III	45 (55.6)	13 (52.0)		
IV	8 (9.9)	3 (12.0)		
Scar area (cm^2)	3.6 (3, 4.1)	4.4 (4, 5.2)	-4.36	< 0.001
VSS score	5 (5, 6)	6 (6, 7)	-4.64	< 0.001
Scar location			-	0.793
Upper eyelid/Periorbital area	22 (27.2)	9 (36.0)		
Nasal area	3 (3.7)	2 (8.0)		
Forehead/Frontal area	29 (35.8)	6 (24.0)		
Eyebrow/Supraorbital ridge	6 (7.4)	2 (8.0)		
Perioral area	5 (6.2)	2 (8.0)		
Cheek/Zygomatic area	5 (6.2)	2 (8.0)		
Mandibular/Submandibular area	11 (13.6)	2 (8.0)		
Laser energy (mJ)	19 (16, 21)	22 (20, 24)	-3.73	< 0.001
No. of sessions	3 (2, 3)	3 (3, 3)	-1.44	0.151

VSS: Vancouver Scar Scale.

Discussion

This retrospective study systematically analyzed the clinical characteristics of patients with post-traumatic facial hypertrophic scars treated with fractional CO_2 laser therapy and identified factors associated with the duration of postoperative erythema. Patients who experienced prolonged erythema were generally older and had larger scar areas, higher VSS scores, and higher laser energy settings. Subsequent correlation analyses confirmed that these variables were positively associated with erythema duration, suggesting that both patient-specific factors and treatment parameters contribute to the persistence of post-laser erythema. Overall, the findings of this study emphasize that patient age, scar severity, and laser treatment parameters should be carefully considered during preoperative evaluation. Anticipating the risk of prolonged erythema may help clinicians design personalized treatment protocols and postoperative care plans, thereby improving recovery outcomes and patient satisfaction.

A previous study reported that the incidence of prolonged erythema after fractional CO_2 laser therapy exceeded 40%, which was higher than that observed in our cohort. This discrepancy may be attributed to differences in patient age, laser energy settings, and treatment frequency, as the previous study included older patients who received higher energy levels and uniformly underwent four treatment sessions [18]. The impact of age on post-laser response may be related to decreased skin repair capacity and reduced vascular reactivity in older individuals. Age-related impairments in inflammatory regulation and epithelial regeneration could further contribute to prolonged erythema [19, 20]. In addition, meta-analyses have demonstrated that early intervention with fractional laser therapy leads to better clinical outcomes and fewer complications compared with late-stage treatments [21]. In our study, patients with prolonged erythema were generally older, which may reflect both intrinsic age-related changes in skin biology and a longer duration of scarring prior to treatment. Although our cohort included both pediatric and adult patients, all

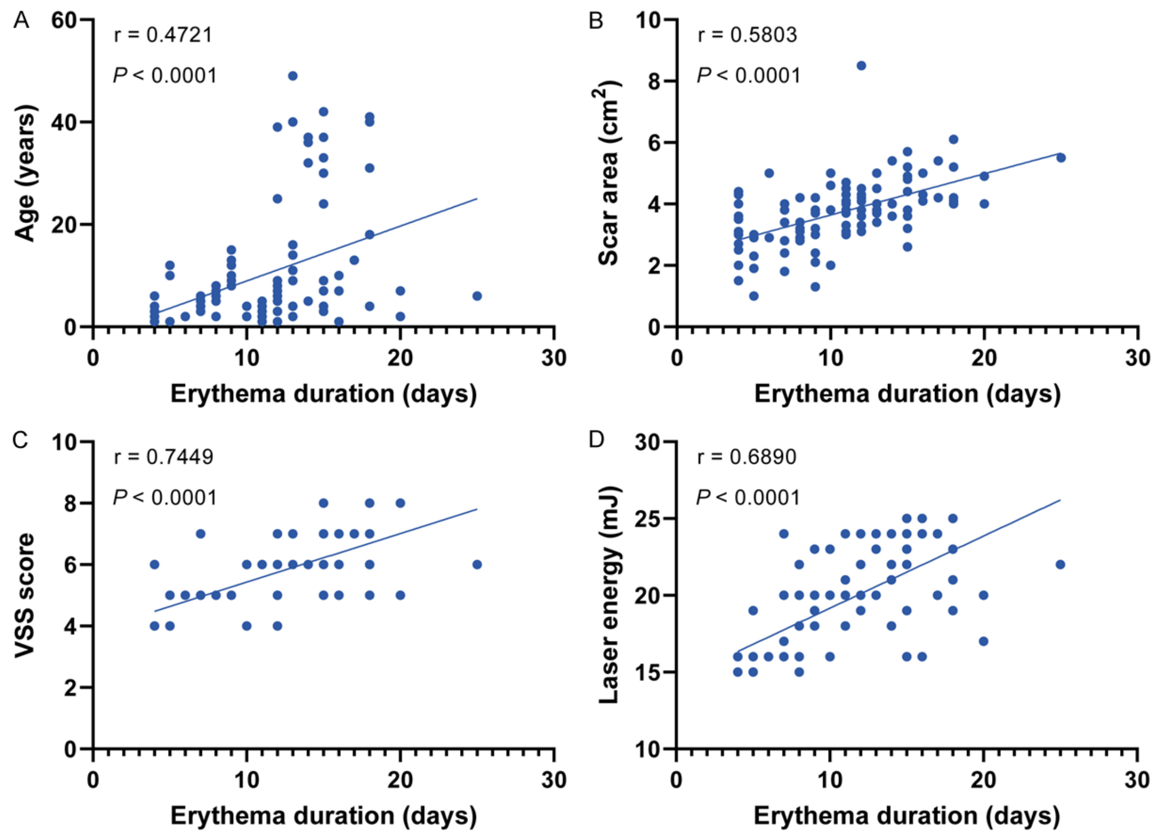

Figure 2. Correlation between erythema duration and continuous variables. A. Positive correlation between age and erythema duration; B. Positive correlation between scar area and erythema duration; C. Strongest positive correlation observed between VSS score and erythema duration; D. Positive correlation between laser energy and erythema duration. VSS: Vancouver Scar Scale.

Table 5. Comparison of educational level, lifestyle factors, and comorbidities between short- and long-duration erythema groups in adult patients (n [%])

Variable	Short-duration group (n = 7)	Long-duration group (n = 9)	Statistic	*P* value
Educational level			-	1.000
Junior high school	1 (14.3)	2 (22.2)		
Senior high school	3 (42.9)	4 (44.4)		
College/University	3 (42.9)	3 (33.3)		
Smoking status			-	1.000
Yes	3 (42.9)	5 (55.6)		
No	4 (57.1)	4 (44.4)		
Alcohol consumption			-	0.615
Yes	4 (57.1)	3 (33.3)		
No	3 (42.9)	6 (66.7)		
Comorbidities			-	0.132
Diabetes mellitus	0 (0.0)	3 (33.3)		
Hypertension	2 (28.6)	0 (0.0)		

were treated under standardized laser parameters and outcome evaluation protocols. Furthermore, age was analyzed as a continuous variable in the statistical model, minimizing the potential confounding effect of age differences.

Scar area and VSS score reflect the extent and severity of scarring. Pathological features such as increased vascular density, disorganized collagen architecture, and basement membrane remodeling in hypertrophic scars may amplify the inflammatory response triggered by laser therapy [22]. Consequently, patients with more severe scars are more likely to experience prolonged erythema. Among treatment parameters, laser energy is a critical determinant of the depth and extent of thermal injury [23]. Patients with higher VSS scores typically require higher energy

Table 6. Associations between scar location and Fitzpatrick skin type with postoperative edema or hyperpigmentation (n [%])

Variable	Edema (n = 39)	No Edema (n = 67)	*P* value	PIH (n = 46)	No PIH (n = 60)	*P* value
Scar location			0.163			0.060
Upper eyelid/Periorbital area	13 (33.3)	18 (26.9)		16 (34.8)	15 (25.0)	
Nasal area	3 (7.7)	2 (3.0)		3 (6.5)	2 (3.3)	
Forehead/Frontal area	9 (23.1)	26 (38.8)		10 (21.7)	25 (41.7)	
Eyebrow/Supraorbital ridge	1 (2.6)	7 (10.4)		2 (4.3)	6 (10.0)	
Perioral area	2 (5.1)	5 (7.5)		2 (4.3)	5 (8.3)	
Cheek/Zygomatic area	3 (7.7)	4 (6.0)		6 (13.0)	1 (1.7)	
Mandibular/Submandibular area	8 (20.5)	5 (7.5)		7 (15.2)	6 (10.0)	
Fitzpatrick skin type			0.021			0.111
I	3 (7.7)	0 (0.0)		1 (2.2)	2 (3.3)	
II	10 (25.6)	24 (35.8)		11 (23.9)	23 (38.3)	
III	19 (48.7)	39 (58.2)		26 (56.5)	32 (53.3)	
IV	7 (17.9)	4 (6.0)		8 (17.4)	3 (5.0)	

PIH: Post-inflammatory hyperpigmentation.

settings to achieve adequate treatment depth, which may enhance therapeutic efficacy but simultaneously increase the risk of adverse reactions [1, 24]. Our findings align with these principles, demonstrating that patients with prolonged erythema exhibited significantly higher VSS scores and larger scar areas. While previous studies have suggested that systemic metabolic status may influence scar formation and healing outcomes, we did not observe significant associations between erythema duration and educational level, smoking, alcohol consumption, or comorbidities such as hypertension and diabetes in this study [25, 26]. These findings suggest that erythema, as a localized tissue response to laser treatment, is primarily determined by local biological characteristics and treatment-induced injury rather than by systemic health or lifestyle factors.

Previous studies have reported highly variable incidence rates of PIH following fractional CO_2 laser therapy, ranging from 0 to 100%, with general agreement that patients with higher Fitzpatrick skin types are at greater risk [8, 27]. This increased susceptibility is primarily attributed to the higher melanin content in darker skin, which predisposes individuals to melanocyte hyperactivity and pigmentary alteration following inflammation [28, 29]. In our cohort, 46 of the 106 patients developed PIH; however, no statistically significant association was identified between Fitzpatrick skin type and PIH occurrence. High energy settings and dense scanning patterns are known to increase the depth of thermal injury and inflammatory response, thereby elevating the risk of edema and other complications [24]. The anatomical location of scars may also influence complication rates. Previous studies have demonstrated that areas such as the eyelids and neck, due to their abundant vasculature and loose connective tissue, are more prone to edema following laser treatment [30]. Interestingly, in our study, no significant difference in scar location was observed between patients with and without edema. However, a significant difference was detected in the distribution of Fitzpatrick skin types between these groups. Given the unclear physiological relationship between skin type and edema, as well as the small number of patients with Fitzpatrick type I and IV (all participants were of Chinese ethnicity), this finding should be interpreted with caution and warrants further validation.

This study has several limitations. First, as a single-center retrospective analysis, it is subject to inherent information and selection bias. Second, variables such as skin type and scar location were unevenly distributed, and some subgroups had small sample sizes, which may have reduced the statistical power of the analysis. Third, the assessment of erythema duration was partly based on physician evaluation and patient self-report, introducing a degree of subjectivity. Future studies could incorporate image-based or device-assisted quantification to enhance measurement accuracy. In addition, postoperative adherence to wound care instructions was not controlled in this study and may have influenced the outcomes. Moreover, we did not perform a detailed comparison of adverse events or treatment parameters between younger children and adult patients stratified by erythema duration, which may limit the generalizability of the findings across age groups. Therefore, future research with larger, multicenter cohorts is warranted to validate these findings and to identify optimal strategies for managing postoperative responses. Furthermore, given the current lack of standardized guidelines for laser parameter settings in pediatric patients, further efforts are needed to establish consensus recommendations that enhance treatment safety and consistency in this vulnerable population.

Conclusion

Despite its limitations, this study provides valuable insights into the clinical predictors of postoperative erythema following fractional CO_2 laser therapy. The findings indicate that patient age, scar severity, and treatment intensity should be carefully considered during preoperative evaluation. Anticipating erythema duration may assist clinicians in designing individualized treatment and postoperative care strategies, thereby optimizing therapeutic outcomes and improving patient satisfaction.

Disclosure of conflict of interest

None.

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