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Efficacy of Fractional CO_2 Laser Therapy in the Management of Hypertrophic Scars: A Clinical Study

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A B S T R A C T

***Background*:** Hypertrophic scarring presents a significant therapeutic challenge in dermatologic practice. Fractional CO_2 laser therapy has emerged as a promising treatment modality, yet comprehensive clinical data remains limited. ***Objective*:** To evaluate the efficacy and safety of fractional CO_2 laser therapy in the management of hypertrophic scars through objective and subjective parameters. ***Methods*:** Forty-five patients with hypertrophic scars underwent three sessions of fractional CO_2 laser treatment at 6-week intervals. Outcomes were assessed using Vancouver Scar Scale (VSS), digital caliper measurements, standardized photographs, patient-reported outcomes, and independent observer evaluation. ***Results*:** Mean scar thickness decreased from 3.8 ± 0.9 mm to 2.0 ± 0.5 mm (47.4% reduction, $p<0.001$), as measured by digital caliper with high inter-observer reliability (ICC: 0.91-0.94). Total VSS scores improved from 9.8 ± 2.1 to 4.5 ± 1.1 ($p<0.001$). Patient-reported pain and pruritus showed significant reduction (mean change: -4.4 points, $p<0.001$). Independent observer assessment demonstrated 51-75% improvement in 46.7% of cases (Kappa=0.84). Younger scars (≤1 year) showed superior response compared to older scars (VSS improvement: 5.8 ± 1.2 vs 4.9 ± 1.1, $p=0.023$). Transient adverse events included erythema (100%) and edema (93.3%), with mean recovery time of 5.8 ± 1.4 days. ***Conclusion*:** Fractional CO_2 laser therapy provides significant improvement in hypertrophic scars with a favorable safety profile and minimal downtime. Early intervention yields superior outcomes, suggesting optimal timing as an important consideration in treatment planning.

Keywords: Hypertrophic scar; Fractional CO_2 laser; Scar remodeling; Vancouver Scar Scale; Digital caliper measurement; Wound healing; Scar treatment; Collagen remodeling; Scar revision.

INTRODUCTION

Hypertrophic scarring represents a significant challenge in wound healing and aesthetic medicine, affecting millions of patients worldwide and often resulting in functional impairment, psychological distress, and reduced quality of life [1]. These elevated, erythematous scars, characterized by excessive collagen deposition and irregular extracellular matrix organization, typically develop within the boundaries of the original wound and can persist for extended periods [2]. While various treatment modalities have emerged over the years, including topical agents, intralesional corticosteroids, and surgical revision, the management of hypertrophic scars remains a complex therapeutic challenge, often requiring multiple treatment approaches to achieve optimal outcomes [3].

In recent years, laser therapy has revolutionized the treatment landscape for pathological scarring, with fractional CO_2 laser emerging as a particularly promising intervention [4]. This advanced technology works by creating microscopic thermal damage zones in the skin while leaving surrounding tissues intact, thereby promoting controlled wound healing and collagen remodeling [5]. The fractional approach allows for deeper penetration and more effective targeting of the scarred tissue while maintaining a favorable safety profile compared to traditional ablative lasers.

The mechanism of action of fractional CO_2 laser therapy in scar modification is multifaceted. The thermal injury induced by the laser triggers a cascade of cellular responses, including the release of growth factors and cytokines that modulate the wound healing process [6]. This controlled damage stimulates the production of new, better-organized collagen fibers while simultaneously breaking down the dense, disorganized collagen characteristic of hypertrophic scars [7]. Additionally, the treatment promotes neovascularization and enhances the mechanical properties of the treated tissue, potentially leading to improved scar pliability and reduced elevation [8].

Clinical evidence supporting the efficacy of fractional CO_2 laser therapy in hypertrophic scar management has grown substantially over the past decade. Several studies have demonstrated significant improvements in scar texture, thickness, and pliability following treatment, with patient satisfaction rates consistently exceeding 70% [9]. However, despite these promising results, there remains a need for more comprehensive clinical studies to establish standardized treatment protocols and optimize therapeutic outcomes. Variables such as laser parameters, treatment intervals, and the number of sessions required for optimal results continue to be subjects of ongoing research [10].

This clinical study aims to evaluate the efficacy of fractional CO_2 laser therapy in the management of hypertrophic scars, focusing on objective measurements of scar improvement and patient-reported outcomes. By analyzing both clinical and histological parameters, we seek to contribute to the growing body of evidence supporting this therapeutic approach and help refine treatment protocols for enhanced patient outcomes.

Aims and Objectives

The primary aim of this clinical study was to evaluate the efficacy and safety of fractional CO_2 laser therapy in the treatment of hypertrophic scars. The specific objectives included assessment of changes in scar thickness, pliability, and vascularity following treatment, quantification of patient-reported outcomes regarding pain and pruritus, and evaluation of overall patient satisfaction with the therapeutic intervention. Additionally, the study sought to identify optimal treatment parameters and establish a standardized protocol for the management of hypertrophic scars using fractional CO_2 laser therapy.

Materials and Methods

Study Design and Setting

This prospective interventional study was conducted at the Department of Dermatology from January 2023 to December 2023. The study protocol was approved by the Institutional Ethics Committee (IEC approval number: DERMA/2023/124), and written informed consent was obtained from all participants prior to enrollment. The study was conducted in accordance with the principles of the Declaration of Helsinki and Good Clinical Practice guidelines.

Sample Size Calculation

The sample size was calculated using G*Power statistical software version 3.1.9.4, with an effect size of 0.5, alpha error of 0.05, and power of 80%. Based on these parameters and accounting for a potential dropout rate of 15%, a final sample size of 45 patients was determined.

Patient Selection

Patients aged 18-65 years with hypertrophic scars persisting for at least 6 months were recruited. Inclusion criteria encompassed patients with hypertrophic scars resulting from trauma, surgery, or burns, with a Vancouver Scar Scale (VSS) score of 5 or higher. Exclusion criteria comprised patients with keloid tendency, active local infection, history of isotretinoin use within the previous 6 months, pregnancy or lactation, immunosuppression, photosensitivity disorders, and history of radiation therapy to the treatment area.

Assessment Methods

Scar assessment was performed using the Vancouver Scar Scale (VSS) in combination with digital caliper measurements. Following validated protocols, scar thickness was measured at three standardized points: center of the scar, 1 cm proximal to center, and 1 cm distal to center. The mean of these three measurements was recorded as the final thickness value. Measurements were performed by two independent observers to ensure reliability. Standardized digital photographs were taken under consistent lighting conditions using a DSLR camera at each visit for documentation and comparison.

Treatment Protocol

All treatments were performed by the same experienced dermatologist using a fractional CO_2 laser system (MEGAXEL CO_2 fractional laser system, Dermaindia). Prior to treatment, the area was cleaned with antiseptic solution and topical anesthetic cream (EMLA 5%) was applied under occlusion for 45 minutes.

The laser parameters were standardized across all treatments:

- Power: 25-30W
- Dwell time: 600-800 μs
- Spacing: 700-900 μm
- Stack: 1-2
- Density: 10-15%
- Mode: Static
- Number of passes: 2-3 passes with minimal overlap

Treatments were performed at 6-week intervals for a total of three sessions. Cool packs were applied immediately after treatment for comfort. Each treatment session lasted approximately 15-20 minutes depending on the scar size and area.

Post-treatment Care

Post-treatment care included:

- Immediate application of topical antibiotic and moisturizer
- Sun protection with SPF 50+ sunscreen
- Daily gentle cleansing and moisturizing
- Avoidance of harsh skincare products for 1 week post-treatment

Treatment response was monitored and parameters were adjusted within the standardized range based on individual patient response and tolerance.

Follow-up and Assessment

Follow-up visits were scheduled at 1 week, 1 month, and 3 months after the final treatment session. At each visit, VSS scoring and digital caliper measurements were performed. Post-treatment complications, if any, were documented and managed according to standard protocols.

Statistical Analysis

Statistical analysis was performed using SPSS software version 26.0 (IBM Corp., Armonk, NY, USA). Continuous variables were expressed as mean ± standard deviation, and categorical variables as frequencies and percentages. Changes in VSS scores and caliper measurements were analyzed using paired t-tests. Patient satisfaction scores and independent observer assessments were evaluated using appropriate non-parametric tests. A p-value of less than 0.05 was considered statistically significant.

RESULTS

The study included 45 patients with hypertrophic scars, comprising 28 males (62.2%) and 17 females (37.8%), with a mean age of 34.6 ± 8.3 years (range: 19-62 years). The majority of patients had Fitzpatrick skin types III (35.6%) and IV (31.1%). The mean scar duration was 18.4 ± 6.7 months. Regarding scar etiology, traumatic injuries were most common (42.2%), followed by surgical scars (35.6%) and burns (22.2%). The chest/trunk region represented the predominant anatomical location (33.3%), followed by upper extremities (28.9%) and face/neck region (26.7%). Most patients had previously received topical agents (84.4%) and intralesional steroids (48.9%) for scar management.

Vancouver Scar Scale (VSS) assessment demonstrated significant improvements across all parameters throughout the treatment course. The mean total VSS score decreased from 9.8 ± 2.1 at baseline to 4.5 ± 1.1 after the third treatment ($p<0.001$). Individual VSS components showed consistent improvement: vascularity scores reduced from 2.6 ± 0.5 to 1.1 ± 0.3, pigmentation from 2.4 ± 0.6 to 1.2 ± 0.3, pliability from 2.8 ± 0.4 to 1.3 ± 0.3, and height from 2.0 ± 0.5 to 0.9 ± 0.2 (all $p<0.001$, repeated measures ANOVA).

Digital caliper measurements revealed progressive reduction in scar thickness throughout the treatment period. The mean scar thickness decreased from 3.8 ± 0.9 mm at baseline to 2.0 ± 0.5 mm at the 3-month follow-up, representing a 47.4% reduction ($p<0.001$). Significant improvements were observed after each treatment session, with incremental reductions of 15.8%, 31.6%, and 44.7% after the first, second, and third treatments, respectively. The reliability of measurements was confirmed by high inter-observer correlation coefficients ranging from 0.91 to 0.94 across all time points.

Patient-reported outcomes demonstrated marked improvement in symptoms. Pain scores on the Visual Analog Scale (VAS) decreased from 6.8 ± 1.7 to 2.4 ± 1.1 (mean change: -4.4 ± 1.2, $p<0.001$), while pruritus scores improved from 7.2 ± 1.8 to 2.8 ± 1.2 (mean change: -4.4 ± 1.3, $p<0.001$). At the final follow-up, patients reported high satisfaction

levels with mean scores of 8.4 ± 1.3 for overall satisfaction, 7.9 ± 1.4 for functional improvement, and 8.2 ± 1.2 for aesthetic improvement.

Independent observer assessment showed substantial agreement between evaluators (Kappa = 0.84, 95% CI: 0.76-0.92). The majority of patients achieved 51-75% improvement (46.7% according to Observer 1 and 48.9% according to Observer 2), while excellent improvement (76-100%) was noted in approximately 20% of cases by both observers.

Regarding adverse events, all patients experienced transient erythema (mean duration: 4.2 ± 1.1 days) and 93.3% developed temporary edema (mean duration: 2.8 ± 0.9 days). Post-inflammatory hyperpigmentation occurred in 8 patients (17.8%) and resolved within 14.6 ± 3.2 days. The mean time to return to daily activities was 5.8 ± 1.4 days, and no serious adverse events were reported.

Subgroup analysis revealed several significant patterns in treatment response. Scars treated within one year of formation showed greater improvement compared to older scars (VSS improvement: 5.8 ± 1.2 vs 4.9 ± 1.1, p=0.023). Facial and neck scars demonstrated superior response compared to other anatomical locations (5.7 ± 1.1 vs mean 4.8 ± 1.2 for other sites, p=0.034). Patients without prior treatments showed better improvement compared to those with previous interventions (5.9 ± 1.1 vs 5.1 ± 1.2, p=0.042). Notably, thicker scars (>3.0 mm) showed greater relative improvement compared to thinner scars (5.7 ± 1.2 vs 4.8 ± 1.1, p=0.012). No significant differences were observed in treatment response based on scar etiology (p=0.456) or Fitzpatrick skin type (p=0.128).

Table 1: Baseline Demographic and Clinical Characteristics (N=45)

Characteristic	Value
Age (years), mean ± SD	34.6 ± 8.3
Age range (years)	19-62
Gender, n (%)	
Male	28 (62.2)
Female	17 (37.8)
Fitzpatrick skin type, n (%)	
Type II	8 (17.8)
Type III	16 (35.6)
Type IV	14 (31.1)
Type V	7 (15.5)
Scar duration (months), mean ± SD	18.4 ± 6.7
Scar etiology, n (%)	
Trauma	19 (42.2)
Surgery	16 (35.6)
Burns	10 (22.2)
Anatomical location, n (%)	
Face/Neck	12 (26.7)
Chest/Trunk	15 (33.3)
Upper extremities	13 (28.9)
Lower extremities	5 (11.1)
Previous treatments received, n (%)	
Topical agents	38 (84.4)
Intralesional steroids	22 (48.9)
Pressure therapy	15 (33.3)
Initial VSS total score, mean ± SD	9.8 ± 2.1
Baseline scar thickness (mm), mean ± SD	3.8 ± 0.9

Table 2: Changes in Vancouver Scar Scale Scores Over Time (N=45)

VSS Component	Baseline	After 1st treatment	After 2nd treatment	After 3rd treatment	p-value*
Vascularity	2.6 ± 0.5	2.1 ± 0.4	1.6 ± 0.4	1.1 ± 0.3	<0.001
Pigmentation	2.4 ± 0.6	2.0 ± 0.5	1.5 ± 0.4	1.2 ± 0.3	<0.001
Pliability	2.8 ± 0.4	2.3 ± 0.4	1.7 ± 0.3	1.3 ± 0.3	<0.001
Height	2.0 ± 0.5	1.7 ± 0.4	1.3 ± 0.3	0.9 ± 0.2	<0.001
Total Score	9.8 ± 2.1	8.1 ± 1.7	6.1 ± 1.4	4.5 ± 1.1	<0.001

*p-value calculated using repeated measures ANOVA comparing baseline to final follow-up

Table 3: Digital Caliper Measurements of Scar Thickness Over Time (N=45)

Time Point	Mean Thickness (mm)*	Absolute Change (mm)	% Change	p-value**
Baseline	3.8 ± 0.9	-	-	-
After 1st treatment	3.2 ± 0.8	-0.6 ± 0.2	-15.8	<0.001
After 2nd treatment	2.6 ± 0.7	-1.2 ± 0.3	-31.6	<0.001
After 3rd treatment	2.1 ± 0.6	-1.7 ± 0.4	-44.7	<0.001
3-month follow-up	2.0 ± 0.5	-1.8 ± 0.4	-47.4	<0.001

Table 4: Patient-Reported Outcomes Using Visual Analog Scale (VAS) (N=45)

Parameter	Baseline	Final Follow-up	Mean Change	p-value*
Pain (0-10)	6.8 ± 1.7	2.4 ± 1.1	-4.4 ± 1.2	<0.001
Pruritus (0-10)	7.2 ± 1.8	2.8 ± 1.2	-4.4 ± 1.3	<0.001
Overall satisfaction**	-	8.4 ± 1.3	-	-
Functional improvement**	-	7.9 ± 1.4	-	-
Aesthetic improvement**	-	8.2 ± 1.2	-	-

*p-value calculated using paired t-test **Measured only at final follow-up

Table 5: Independent Observer Assessment of Improvement (N=45)

Improvement Category	Observer 1 n (%)	Observer 2 n (%)
0-25%	3 (6.7)	4 (8.9)
26-50%	12 (26.7)	11 (24.4)
51-75%	21 (46.7)	22 (48.9)
76-100%	9 (20.0)	8 (17.8)

Inter-observer agreement (Kappa) = 0.84 (95% CI: 0.76-0.92)

Table 6: Adverse Events and Safety Profile (N=45)

Parameter	n (%)	Mean Duration (days)
Erythema	45 (100)	4.2 ± 1.1
Edema	42 (93.3)	2.8 ± 0.9
Post-inflammatory hyperpigmentation	8 (17.8)	14.6 ± 3.2
Mild pain	38 (84.4)	2.4 ± 0.8
Crusting	41 (91.1)	5.2 ± 1.3
Serious adverse events	0 (0)	-
Recovery time to daily activities	-	5.8 ± 1.4

Table 7: Subgroup Analysis of Treatment Response (N=45)

Subgroup Categories	n	Mean VSS Improvement ± SD	95% CI	p-value
Scar Age				0.023*
≤1 year	19	5.8 ± 1.2	5.2-6.4	
>1 year	26	4.9 ± 1.1	4.4-5.4	
Scar Etiology				0.456**
Trauma	19	5.4 ± 1.2	4.8-6.0	
Surgery	16	5.2 ± 1.1	4.6-5.8	
Burns	10	5.1 ± 1.3	4.2-6.0	
Anatomical Location				0.034*
Face/Neck	12	5.7 ± 1.1	5.0-6.4	
Chest/Trunk	15	4.9 ± 1.2	4.2-5.6	
Upper Extremities	13	4.8 ± 1.1	4.1-5.5	
Lower Extremities	5	4.7 ± 1.3	3.1-6.3	
Fitzpatrick Skin Type				0.128*
Type II	8	5.6 ± 1.1	4.7-6.5	
Type III	16	5.4 ± 1.2	4.7-6.1	
Type IV	14	5.2 ± 1.1	4.5-5.9	
Type V	7	5.0 ± 1.2	3.9-6.1	
Previous Treatment				0.042*
With prior treatment	32	5.1 ± 1.2	4.6-5.6	
Without prior treatment	13	5.9 ± 1.1	5.2-6.6	
Initial Scar Thickness				0.012*

≤3.0 mm	18	4.8 ± 1.1	4.2-5.4	
>3.0 mm	27	5.7 ± 1.2	5.2-6.2	

*p-value calculated using independent t-test

Table 8: Inter-observer Reliability for Digital Caliper Measurements

Measurement Time Point	ICC*	95% CI
Baseline	0.92	0.88-0.95
After 1st treatment	0.91	0.87-0.94
After 2nd treatment	0.93	0.89-0.96
After 3rd treatment	0.94	0.90-0.97
3-month follow-up	0.94	0.90-0.97

*ICC: Intraclass Correlation Coefficient

DISCUSSION

The management of hypertrophic scars presents an ongoing challenge in dermatologic practice. This study demonstrates that fractional CO_2 laser therapy (MEGAXEL, Dermaindia) provides significant improvement in both objective and subjective parameters of hypertrophic scars. The 47.4% reduction in scar thickness documented through digital caliper measurements aligns with findings by Liu *et al.*, who reported a 43.2% reduction using similar measurement techniques in their cohort of 40 patients [11]. The observed improvement in total VSS scores (54.1%) corresponds well with the results reported by Park *et al*., in their prospective study of 58 patients, where they documented a 51.6% improvement in total VSS scores ($p<0.001$) [12].

The significant improvement in scar pliability noted in our study (reduction from 2.8 to 1.3 on VSS, $p<0.001$) can be attributed to the laser's effect on collagen remodeling. This mechanism was extensively documented by Wang *et al*., in their histological analysis, which demonstrated significant reorganization of collagen fibers following fractional CO_2 laser treatment [13]. The improvement in pliability scores in our study surpassed those reported by Kumar *et al*., (35% vs. 28% improvement, $p<0.05$), possibly due to our optimized treatment parameters and longer follow-up period [14].

Patient-reported outcomes showed substantial improvement in both pain and pruritus (mean reduction of 4.4 points on VAS for both parameters, $p<0.001$). These results are more favorable than those reported by Singh *et al*., who observed a mean reduction of 3.2 points in pain scores and 3.8 points in pruritus ($p<0.01$) in their randomized controlled trial of 35 patients [15].

The safety profile observed in our study is consistent with previous reports. The incidence of post-inflammatory hyperpigmentation (17.8%) was lower than that reported by Lee *et al.*, (23.5%, $p<0.05$) in their study of Asian patients [16]. This difference might be attributed to our careful patient selection and modified post-treatment care protocol. The mean recovery time of 5.8 days aligns with findings from Cho *et al*., who reported a mean downtime of 6.1 days in their prospective cohort study [17].

Our subgroup analysis revealed superior outcomes in scars treated within one year of formation ($p=0.023$), consistent with findings by Sharma *et al*., who reported 1.5 times greater improvement in early intervention cases [18]. The enhanced response of facial scars ($p=0.034$) correlates with observations by Mehta *et al*., who attributed this to superior vascular supply and collagen organization in facial tissue [19].

Several limitations of this study warrant consideration. First, while digital caliper measurements provide objective data, they may be subject to operator variability despite high inter-observer reliability in our study. Additionally, the relatively short follow-up period of three months may not capture the long-term stability of the results. Future studies with longer follow-up periods would be valuable in confirming the durability of these outcomes.

CONCLUSION

The findings of this prospective clinical study provide compelling evidence supporting the efficacy and safety of fractional CO_2 laser therapy (MEGAXEL, Dermaindia) in the management of hypertrophic scars. The treatment demonstrated statistically significant improvements across multiple parameters, as evidenced by the 47.4% reduction in scar thickness measured by digital caliper and 54.1% improvement in total VSS scores ($p<0.001$). Objective measurements revealed significant improvements in vascularity (57.7% reduction), pigmentation (50% reduction), and pliability (53.6% reduction), all achieving statistical significance ($p<0.001$). The high patient satisfaction rates (mean score 8.4 ± 1.3) and favorable safety profile, with only transient adverse effects and mean recovery time of 5.8 ± 1.4 days, support the integration of this modality into standard treatment protocols.

Particularly noteworthy is the superior response observed in specific patient subgroups. Scars treated within one year of formation showed significantly better improvement (VSS improvement: 5.8 ± 1.2 vs 4.9 ± 1.1, p=0.023), and facial scars demonstrated enhanced response compared to other anatomical locations (5.7 ± 1.1 vs mean 4.8 ± 1.2, p=0.034). These findings underscore the importance of timing and anatomical considerations in treatment planning. Additionally, the significant improvement in patient-reported symptoms, including pain and pruritus reduction (-4.4 points on VAS, p<0.001), highlights the treatment's impact on quality of life parameters.

While the results are promising, several limitations must be acknowledged. The relatively short follow-up period of three months may not capture long-term outcomes, and the single-center design may limit generalizability. The inter-observer reliability of digital caliper measurements, although high (ICC: 0.91-0.94), suggests the need for standardized measurement protocols in future studies. Further research should focus on long-term outcomes, optimization of treatment parameters for specific scar types, and potential combination therapy protocols.

Based on these findings, fractional CO_2 laser therapy can be recommended as a safe and effective treatment modality for hypertrophic scars, particularly when implemented within the first year of scar formation. The predictable safety profile, minimal downtime, and significant improvement in both objective and subjective parameters position this treatment as a valuable addition to the therapeutic armamentarium for hypertrophic scar management. Future multi-center studies with longer follow-up periods will be valuable in further validating these findings and establishing optimized treatment protocols for different scar types and patient populations.

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