Lasers in Surgery and Medicine

CLINICAL REPORT

Safety and Effectiveness of a Thermo-Mechanical Fractional System at Low Settings for the Treatment of Photodamage

Eric F. Bernstein[1] | Maggie Wang[2] | Jennifer Wang[3] | J. Lee Pannell[4]

[1]Main Line Center for Laser Surgery, Ardmore, Pennsylvania, USA | [2]Cornell University, Ithaca, New York, USA | [3]State University of New York Downstate Health Sciences University, Brooklyn, New York, USA | [4]Novoxel, Ltd, Netanya, Israel

Correspondence: Eric F. Bernstein (dermguy@dermguy.com)

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ABSTRACT

Objective: To evaluate the efficacy and safety of a thermo-mechanical fractional device for the treatment of photodamaged skin.

Methods and Materials: Twenty-five subjects received three thermo-mechanical fractional device treatments at monthly intervals. Low treatment settings of a 5 ms pulse duration and 100 μm tip protrusion were administered in 1–2 passes. Digital images were evaluated for improvement on the Fitzpatrick Wrinkle Classification Score 3 months after the final treatment. Secondary efficacy endpoints included ratings on a Global Aesthetic Improvement Score and Subject SatIsfaction Questionnaire.

Results: Forty-eight percent of subjects demonstrated a ≥ 1 score improvement in the Fitzpatrick Wrinkle Classification Score, and 96% of subjects demonstrated a good to excellent Global Aesthetic Improvement Score. Sixty-eight percent of subjects were "satisfied" to "very satisfied" with treatment results.

Conclusions: The thermo-mechanical fractional device at low settings is safe and effective for improving signs of photodamage with minimal patient discomfort.

1 | Introduction

Numerous treatments including energy-based devices (EBDs) like lasers, microdermabrasion, chemical peels, and injectables such as dermal fillers and neuromodulators have been used to improve photodamaged skin [1–4]. Each method, while effective in addressing skin texture and appearance, entails a certain degree of risk and recovery time [1–4]. Adverse events range from mild irritation and sensitivity to more severe complications such as blistering, infection, and contact and allergic dermatitis, underscoring the need for safe and efficacious alternatives [3, 5–7].

Lasers and other EBDs that administer energy in a grid pattern covering only a fraction of the skin surface, termed fractionated treatments, have revolutionized revoluationized aesthetic treatments while reducing side effects compared to many treatments covering the full skin surface. These devices create micro-wounds in the epidermis and dermis that initiate the wound healing cascade to the entire treated area despite only treating a portion of the skin surface, including reorganization of the dermal collagen matrix [1]. Among the most popular fractionated devices are the pulsed carbon dioxide (CO_2) laser, other ablative, semi-ablative, or non-ablative lasers, RF microneedling, and ultrasound devices [8–11]. Each device has its benefits and side effects.

The thermo-mechanical fractional device (TMFD) represents a completely novel approach to fractionated treatment of photodamage, acne scarring, and the treatment of dry eye [12–14]. In 2012, Lask and colleagues introduced a prototype thermo-mechanical ablation technology in which a metallic element at 400°C is brought into contact with the skin for 0.1–5 ms at a depth of 50–250 μm, vaporizing the tissue and inducing an inflammatory response [12]. The fractionated tip delivers energy over a portion of the treatment area in a grid pattern resembling a fractionated laser or fractionated radiofrequency device. This and another study have demonstrated the ability of TMFD to create microthermal treatment zones similar to lasers, but with different clinical responses and histologic changes due to the distinct way heat is absorbed by the skin when using lasers versus TMFD [13]. The present study aims to examine the safety and efficacy of TMFD and subject satisfaction with TMFD treatments for the treatment of photodamaged skin using low treatment settings resulting in little to no downtime.

2 | Methods

2.1 | Subjects

Healthy male and female subjects, 18–75 years of age with clinically evident photodamage and Fitzpatrick wrinkle scores ranging from ≥ 2, were eligible for this institutional review board-approved prospective, single-center, single-arm clinical study. Exclusion criteria included pregnancy, dermatitis in the treatment area, isotretinoin treatment within 6 months of study initiation, collagen vascular disease, a history of keloid formation or hypertrophic scarring, previous treatments with lasers or other energy-based devices in the treatment area, botulinum toxin or dermal fillers in the treatment area, and superficial peels or any other facial treatment within 6 months of study initiation.

2.2 | TMFD Device

The TMFD (Tixel, Novoxel Ltd., Netanya, Israel) uses a fractionated treatment tip composed of a metal alloy. The reusable tip is made of a gold-plated copper base clad with a titanium shell at the distal end of the handpiece. The tip's active surface has an array of 81 evenly spaced, blunt pyramids that do not pierce the skin. The blunt pyramids are 1.25 mm in height and have a radius of 100 μm at the peak vertex. The flat back plane of the tip connects to a heater kept at 400°C during treatment [13].

When the user activates the handpiece, a motor advances the tip to the target tissue. Thermal energy is transferred to the skin and creates an array of micro-craters and coagulated tissue without penetrating the epidermis. The amount of thermal energy delivered to the skin is determined by the pulse duration (5–16 ms) and the protrusion distance (100–800 μm), as well as the fixed 400°C temperature. The tip protrusion parameter is the distance through which the heated tip moves beyond the edge of the plastic distance gauge of the handpiece. A greater protrusion distance leads to a greater degree of skin contact with the titanium pyramids, fewer air gaps, and greater thermal transfer. The tip is a heat reservoir. A heater transfers heat to the back side of the tip to maintain its temperature at 400°C. Upon brief contact with the skin, heat is transferred from the titanium shell to the skin. The tip temperature does not change during operation. The reservoir is large enough and is designed to maintain temperature stable at 400°C. Depending upon the treatment settings, treatments can be non-ablative or ablative. Two tips are available: a large tip with 81 (9 × 9) miniature pyramids and a precision tip with 24 (6 × 4) smaller pyramids [14]. The present treatments were administered with the 9 × 9 treatment tip.

2.3 | TMFD Treatment

Subjects received three treatments with the TMFD at 4–6-week intervals. Efficacy and tolerability were evaluated 3 months after the final treatment. Treatments were performed at low treatment settings, using a 5 ms pulse duration and a 100 μm protrusion setting, and either single or double passes. Treated areas included the forehead, cheeks, upper lip, nose, periorbital areas, and chin. Because the study was performed at low settings, topical anesthesia or air cooling was not used. Treatment parameters were determined by the treating physician, who based decisions on prior experience and observed immediate clinical responses.

Subjects received three treatments and efficacy and side-effect assessments were performed before each treatment. Subjects were photographed immediately before treatment and 1 and 3 months following the last treatment. Subjects completed a satisfaction questionnaire at the final 3-month follow-up visit.

2.4 | Assessments

Treatment effect was measured by blinded evaluation of pre- and posttreatment frontal, left lateral, and right lateral images taken using regular flash photography using a professional digital imaging system with a rig and digital video ghosting to ensure nearly identical positioning of the face during each timepoint (Visia CR, Canfield Scientific Inc.). Digital images of both the peri-oral and peri-orbital area were evaluated using the Fitzpatrick Wrinkle Classification Scale (FWCS) [15]. The primary endpoint was the proportion of subjects with a ≥ 1 score improvement on the FWCS at 3 months following the final treatment compared to baseline images as determined by at least three dermatologists. The FWCS were as follows: fine wrinkles with subtle lines (scores 1–3), medium-depth wrinkles with obvious lines (scores 4–6), and medium to deep wrinkles with numerous lines, with or without redundant skin folds (scores 7–9).

Secondary efficacy endpoints included improvements in the Global Aesthetic Improvement Scale (GAIS) score at the final 3-month follow-up compared to baseline scores and patient-reported outcomes as assessed by the Subject Satisfaction Questionnaire. The GAIS-grading scale is shown in Table 1. Safety endpoints included treatment pain as reported by the subject on a visual analog scale (VAS), in which 0 = no pain and 10 = most severe pain. Safety was also evaluated by recording

TABLE 1 | The GAIS-grading scale.

C Score	0	1	2	3	4
Assessment	0% No change	1%–25% Poor	25%–50% Fair	50%–75% Good	75%–100% Excellent

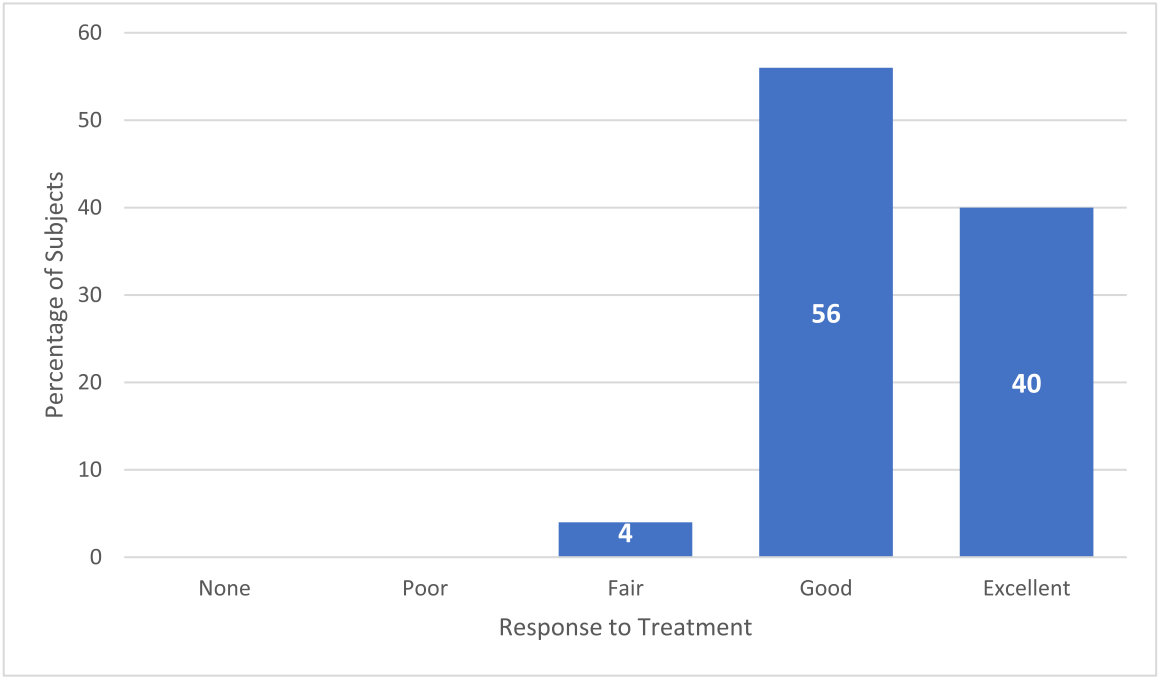

FIGURE 1 | Global Aesthetic Improvement Score (GAIS) results 3 months after the final treatment.

the incidence or absence of adverse events such as bleeding, infection, pigmentary changes, or scarring.

The Subject Satisfaction Questionnaire included three areas of inquiry: (1) I am satisfied with the results of the treatment, (2) I am satisfied with the treatment experience, and (3) I am satisfied that the treatment fulfilled my expectations, with five potential responses. Subjects recorded one of five possible responses including: (1) not satisfied, (2) satisfied to some extent, (3) moderately satisfied, (4) satisfied, or (5) very satisfied.

3 | Results

A total of 25 subjects consisting of 22 females and 3 males were enrolled in the study and treated. The mean age was 52.8 ± 8.9 (mean $\pm$ SD), and ranged between 38 and 70. Participants' Fitzpatrick skin types ranged from I to IV and included: I ($n = 1$), II ($n = 9$), III ($n = 10$), and IV ($n = 5$). Participants' baseline FWCS ranged from 2 to 7. All subjects completed the study including three TMFD treatments and two follow-up visits.

3.1 | FWCS

At 1 month following the final treatment, 28% of subjects demonstrated a ≥ 1 score improvement in FWCS. At 3 months following the final treatment, 48% of subjects achieved a ≥ 1 score improvement in the FWCS at the 3 months posttreatment visit. Among the remaining subjects, 48% showed no change and 4% (one subject) worsened.

The FWCS scores at baseline, 1 month, and 3 months were also compared. The nonparametric Friedman's test was used to test for significant differences among the medians of the three populations, as the data were not normally distributed by the Shapiro–Wilk test. Values were ranked in each population and then compared. Although the median FWCS scores remained constant at 5.0 across all three time points, the test revealed significant differences ($p = 0.0009$) in the mean FWCS scores between the three time points (2.34, 1.98, and 1.68 for baseline, 1 month, and 3 months, respectively). This apparent contradiction can be explained by the changes in the distribution of scores over time. The baseline visit had the most high-ranking values and the 3-month posttreatment visit had more low-ranking values. This suggests that the distribution shapes of FWCS scores changed significantly over the treatment period, with an overall improvement in wrinkle severity over time.

3.2 | GAIS

At 1 month following the final treatment, 84% of subjects had a "good" to "excellent" response to treatment with TMFD. At 3 months following the final treatment, 96% of subjects had a "good" to "excellent" response. The remaining subjects achieved a "fair response" at 1 month and 3 months post-final treatment (Figure 1).

3.3 | Subject Satisfaction Questionnaire

Of the 25 participants, 68% (17/25) of subjects were "satisfied" to "very satisfied" with the treatment results. One hundred percent (25/25) were "satisfied" to "very satisfied" with the treatment experience. Seventy-two percent (18/25) were "satisfied" to "very satisfied" that the treatment fulfilled their expectations. One hundred percent (25/25) of subjects were at least "satisfied to some extent" in all three categories (Figures 2 and 3).

3.4 | Side Effects

Pain during each treatment session was graded by each subject on a VAS. Median pain scores for the first, second, and third treatments were 2.5 (0–4), median (range); 3.0 (0–5); and 2.5 (0–3), respectively. The non-parametric Friedman test was used to test for significant differences among the three treatments, as pain data were not normally distributed as shown by the Shapiro–Wilk test. The differences in pain scores between treatments were not statistically significant ($p = 0.4161$).

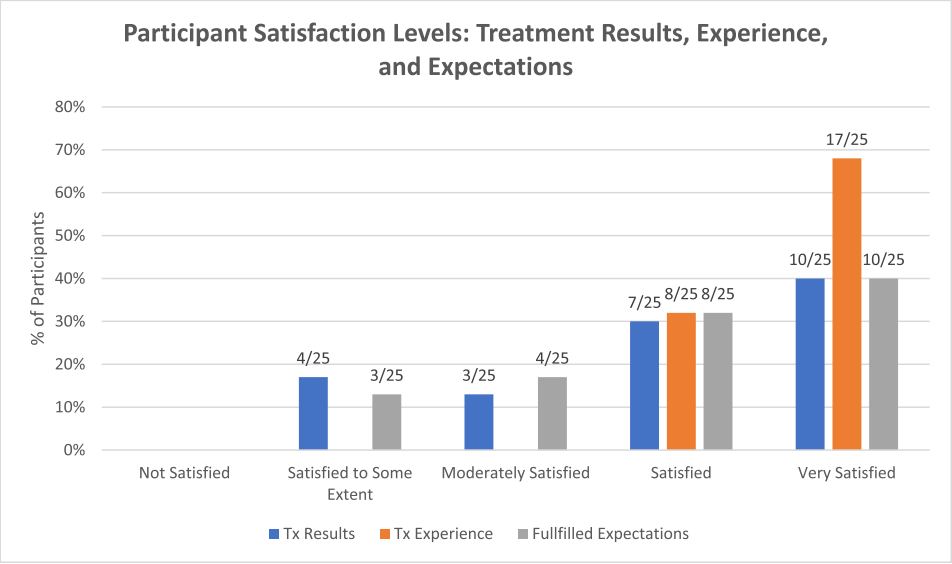

FIGURE 2 | Distribution of subjects among levels of satisfaction with treatment results (Tx Results), satisfaction with treatment experience (Tx Experience), and fulfillment of expectations.

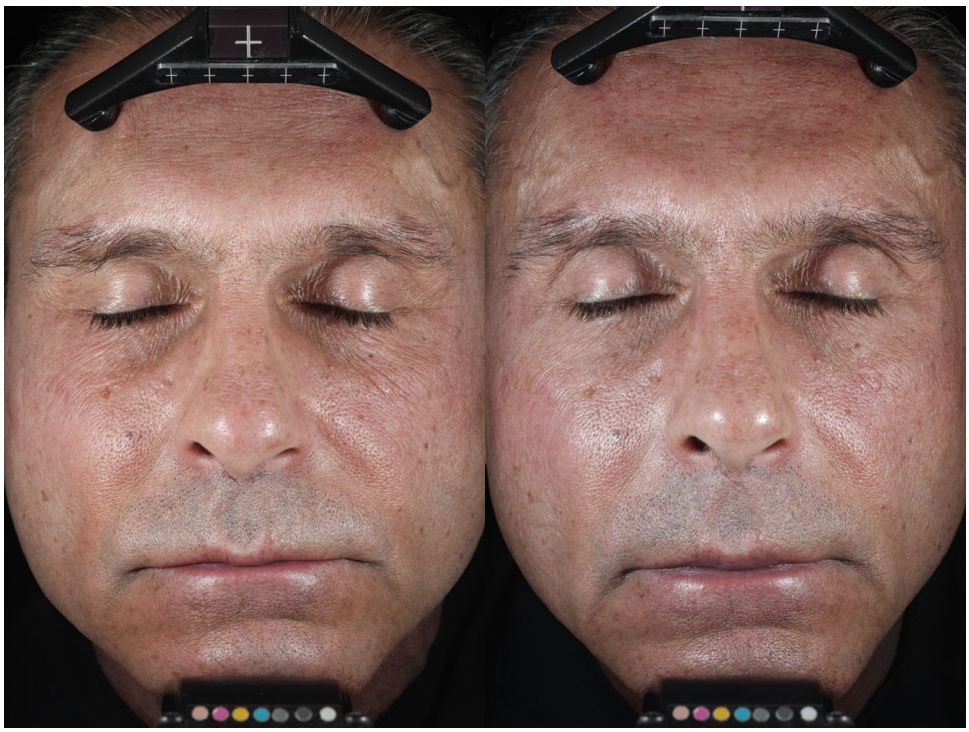

FIGURE 3 | A 59-year-old male (Fitzpatrick type III) before (left) and after (right) three periorbital treatments with the thermo-mechanical fractional device at monthly intervals.

4 | Discussion

This study demonstrates the efficacy, safety, and patient satisfaction of the TMFD in improving the appearance of photodamaged skin. Even at the very low settings in the current study, at the 3-month follow-up visit, nearly half of the subjects showed a ≥ 1 score improvement in the FWCS. The decrease in improvement in one subject's FWCS may be attributed to various factors, such as individual variability in skin response to thermal treatments and external influences on skin condition. At 3 months post-final treatment, 96% of all subjects had a "good" to "excellent" response to treatment on the GAIS. The FWCS results primarily reflect specific changes in wrinkle depth and severity, which showed modest improvements. In contrast, the GAIS evaluates overall aesthetic improvement, encompassing aspects such as skin tone, texture, and radiance, which were perceived more positively overall. The difference between FWCS and GAIS scores highlights the value of using multiple scales in clinical trials to capture both specific clinical changes and broader aesthetic improvements, providing a comprehensive assessment of treatment outcomes.

For patient-reported outcomes, 68% of participants were "satisfied" to "very satisfied" with treatment results, 100% were "satisfied" to "very satisfied" with the treatment experience, and 72% were "satisfied" to "very satisfied" that the treatment fulfilled their expectations. Treatments were extremely well-tolerated and there were no adverse events reported. The pain of treatment was minimal and no topical anesthetic or skin cooling was used.

The settings in the current study were conservative using a large tip size, 5 ms pulse durations and 100 μm protrusion depths, settings lower than those previously published, to evaluate the device's efficacy at its lowest effective parameters, illustrating the versatility of this novel device [13, 14, 16–18]. The objective was to develop treatment parameters with little-to-no downtime for use as a periodic treatment to improve the appearance of photodamaged skin. The TMFD delivers heat, as opposed to light, eliminating the need for the operator and assistants to use protective eyewear during procedures. In addition, the self-sterilization feature removes the need for a disposable tip, which is convenient and limits utilization costs. Based on our clinical experience and study results, a setting of 5 ms contact time and 100 μm protrusion depth with two passes is effective for mild treatments. The majority of patients reported high satisfaction using these settings. While higher settings may achieve more significant results, they often involve increased downtime. We did not adjust treatment settings based on individual patient characteristics such as skin type or wrinkle severity, as the conservative parameters were well-tolerated by all participants.

The safety and efficacy of the TMFD in more aggressive treatment settings are well established in other studies [14, 16, 18, 19]. One prospective, blinded, single-arm clinical study with 51 participants demonstrated high patient comfort, satisfaction, safety, and efficacy of the TMFD for treatment of periorbital wrinkles at 12 ms and 600 μm protrusion settings [16]. TMFD treatment resulted in significant improvement in periorbital wrinkle severity with a high level of inter-rater agreement among physicians evaluating treatment efficacy [16]. Only a single case of treatment-related erythema was reported, which resolved within 2 days [16]. In that study, forced-air cooling was used and topical anesthetics were not applied [16].

In another clinical study that utilized higher protrusion depth settings, TMFD was shown to improve erythema, periorbital wrinkles, irregularities in skin tone, skin laxity, and reduce enlarged pores [14]. In that study, the large, 9 × 9 treatment tip was used administering one to two passes with 0%–30% overlap, a pulse duration of 8–14 ms, and protrusion settings of 500–1000 μm [14]. Erythema and hyperpigmentation were transient, and downtime averaged 1.7 days [14]. TMFD treatments using medium-high settings (10–12-ms pulse durations and 400–700 μm protrusion) have also been shown to treat actinic keratoses [19]. Patients achieved an 81% reduction in actinic keratoses ($p < 0.0001$), with 32% achieving complete clearance with a single treatment, with high patient satisfaction [19].

A large retrospective study of 150 subjects with photodamage ($n = 145$) or acne scars ($n = 5$) was further undertaken to assess the efficacy and tolerability of TMFD's treatment [18]. Out of the 327 treatment sessions analyzed using pulse durations ranging 5–14 ms and protrusion settings ranging from 400 to 1000 μm, only four adverse events were noted, including post-inflammatory hyperpigmentation ($n = 2$), impetigo ($n = 1$), and dermatitis ($n = 1$) following treatment [18].

When compared to traditional fractional CO_2 ablative lasers, TMFD demonstrates a compelling profile. A study using a 10,600 nm fractional CO_2 laser reported that only 42.8% of patients achieved a "mild," "moderate," or "excellent" improvement in wrinkles at 3 months posttreatment [20]. In contrast, 96% of subjects in the current study had a "good" to "excellent" response on the GAIS at the same time point [20]. Although satisfaction rates were similar, with 100% of patients in both studies being "satisfied" to "very satisfied" at 3 months post-treatment, TMFD offered a more favorable safety profile [20]. Median pain scores during TMFD treatments ranged from 2.5 to 3.0 on a ten-point scale, significantly lower than the mean score of 6.29 on an eight-point scale reported in CO_2 laser treatments, where 71.4% of patients described the pain as "severe." [20] Additionally, in the CO_2 laser study, all patients experienced erythema within the first week, with 22.2% still exhibiting signs at 6 months [20]. In contrast, TMFD treatments in our study led to no reports of persistent erythema. Fractional non-ablative lasers are also commonly used in the treatment of photodamaged skin [21]. One study utilizing a fractional non-ablative laser combining wavelengths of 1550 and 1927 nm demonstrated a 21% reduction in fine wrinkling and a 30% decrease in tactile roughness 3 months after the final treatment [21]. Compared to our study, patients in the non-ablative laser study experienced moderate erythema (mean score 1.6 ± 0.5) and mild edema (mean score 0.8 ± 0.7) on average, whereas TMFD treatment resulted in no significant or persistent erythema [21]. Pain levels were described as "tolerable," similar to the minimal pain observed in the current study [21].

Hybrid ablative lasers combining 10,600 nm ablative and 1570 nm non-ablative wavelengths have also been evaluated for

facial rejuvenation [22]. In one study, patients undergoing high-setting single treatments achieved 51%–75% improvement in GAIS scores, with a downtime of 7.3 ± 2.3 days [22]. Erythema resolved within a week for 36.4% of patients, while 18.2% experienced posttreatment hyperpigmentation that resolved within 3 months [22]. The average VAS pain score was 5.8 ± 1.8 on a ten-point scale [22]. A low-to-moderate setting multi-treatment group achieved comparable GAIS scores with a downtime of 4.3 ± 1.6 days [22]. Posttreatment erythema was present in 90.9% of patients but resolved within a week, and no cases of hyperpigmentation were observed [22]. Patient satisfaction averaged 3.4 ± 0.7 on a 4-point scale, and the VAS pain score was 5.2 ± 2.1 [22]. Compared to TMFD, hybrid ablative laser treatments demonstrated longer downtime, higher rates of erythema and hyperpigmentation, and higher pain scores, although both treatments yielded comparable results in GAIS scores and patient satisfaction [22]. A prospective randomized controlled study comparing TMFD to a non-ablative fractional 1565 nm erbium:glass fiber laser found a statistically significant improvement in rhytides from baseline with both treatments with no significant difference between the two groups [23]. There were no differences in the erythema, edema, and downtime [23]. However, the VAS pain score was significantly lower in the TMFD group, indicating better tolerability [23].

The above studies demonstrate the safety and efficacy of TMFD for treating a range of dermatological conditions with minimal downtime or patient discomfort. Our study expands on previous work by demonstrating that a series of treatments with quite conservative settings results in measurable skin improvement with high patient satisfaction and very minimal side effects. Even at higher settings, posttreatment side effects associated with TMFD treatment are typically minimal, and TMFD treatments do not require the use of a smoke evacuator or protective eyewear for operators or assistants [14, 16, 18, 19]. Studies utilizing low treatment settings similar to those of the current study have also demonstrated TMFD's ability to improve topical delivery of drugs, promote wound healing, and treat dry eye disease [24–33]. The use of heat rather than light to improve dry eye disease adds a significant layer of safety by dramatically reducing the risk of iris injury and eliminating the risk of retinal injury. The current study adds to the existing literature and demonstrates TMFD's efficacy in improving signs of photoaging with minimal side effects and high patient satisfaction as monotherapy. In clinical practice, TMFD is virtually always incorporated into a multimodality treatment approach with topical agents, enhancing their absorption and effects.

A limitation of this study is its small sample size, which may limit the generalizability of the study to broader populations, underscoring the need for future RCTs with larger, diverse participant populations to further establish these findings. Another limitation of this study is the lack of long-term evaluation data. Future RCTs could better establish TMFD's long-term efficacy and safety with long-term follow-up periods. While the present study evaluated TMFD as a monotherapy, in clinical practice, TMFD is often integrated into multi-modal treatment regimens to enhance overall outcomes for photodamaged skin. Combining TMFD with topical agents such as retinoids or antioxidants may enhance skin rejuvenation by increasing product absorption due to improved skin permeability. Additionally, TMFD can be used alongside procedures like chemical peels, microdermabrasion, or other laser treatments to achieve synergistic improvements in skin texture, tone, and overall appearance. Future studies could explore these combination approaches to further establish their clinical benefits.

5 | Conclusion

This study demonstrates that the TMFD used at low settings is safe and effective for improving the signs of photodamage, results in high patient satisfaction, with little or no downtime.

Conflicts of Interest

The device manufacturer loaned the treatment device to the authors at no charge for this study. Lee Pannell is employed by Novoxel Ltd. Dr. Bernstein has equity in Novoxel Ltd.

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