

# Ultrapulsed fractional ablative carbon dioxide laser treatment of hypertrophic burn scars: evaluation of an in-patient controlled, standardized treatment approach

Julian Poetschke<sup>1</sup> · Ulf Dornseifer<sup>2</sup> · Matteo Tretti Clementoni<sup>3</sup> · Markus Reinholz<sup>1</sup> · Hannah Schwaiger<sup>1</sup> · Stephanie Steckmeier<sup>1</sup> · Thomas Ruzicka<sup>1</sup> · Gerd G. Gauglitz<sup>1</sup>

Received: 7 February 2017 / Accepted: 29 March 2017  
© Springer-Verlag London 2017

**Abstract** In this study, we aimed to quantify the effects of fractional ablative carbon dioxide laser therapy in the treatment of widespread hypertrophic burn scars. While many different pilot studies have described the potential of the technology and expert groups and current guidelines, alike, recommend its use, the level of evidence for the efficacy of fractional CO<sub>2</sub>-laser treatment for burn scars is currently very low. Ten patients (three male, seven female) with hypertrophic burn scars were treated with a single course of fractional CO<sub>2</sub>-laser therapy in an in-patient controlled setup, using a standardized treatment paradigm. Documentation was based on modern scar scales and questionnaires, like the Vancouver Scar Scale (VSS), Patient and Observer Scar Assessment Scale (POSAS), and Dermatology Life Quality Index (DLQI), as well as state of the art clinical measurements (PRIMOS, Cutometer). Over the course of 6 months after treatment, VSS and POSAS scores showed significant improvement in the rating of scar parameters, as did the quality of life rating according to the DLQI. In the treated scars, surface relief improved significantly, as  $S_{\max}$  decreased by 1893  $\mu\text{m}$  (-36.92%) ( $p = 0.0273$ ) and  $S_z$  by 1615  $\mu\text{m}$  (-36.37%) ( $p = 0.0488$ ). Scar firmness in treated scars could be reduced by 30% after one treatment session, as  $R_0$  improved by 0.0797 mm (+30.38%) ( $p = 0.0212$ ). Fractional ablative

CO<sub>2</sub>-laser treatment is a safe and efficacious option for the treatment of hypertrophic burn scars. While more treatment sessions are required for satisfying results, significant improvement is already apparent after a single course of treatment.

**Keywords** Burn trauma · Burn scar · Widespread hypertrophic scarring · CO<sub>2</sub> laser · Fractional ablative laser · PRIMOS · POSAS · Vancouver Scar Scale · DLQI

## Introduction

Burn trauma is a common form of injury in both developed and undeveloped countries around the world. According to data from the American Burn Association, 486,000 people annually receive medical care because of burn injuries in the USA. Out of these, 40,000 have to be hospitalized including 30,000 requiring treatment in a specialized burn center. Out of all patients admitted to burn centers, 3.2% succumb to their injuries with deaths due to fire and smoke inhalation amounting to 3275 in 2014 [1].

Burn trauma, however, does not only present a challenging task for the treating physician during the acute phase; it often-times continues to bother patients long after their wounds have healed and their hospital stay is over. Burn scars are frequently esthetically unpleasing and, when affecting exposed areas, can become downright stigmatizing. Hypertrophic scarring and the development of contractures also represent common problems. Research has shown that up to 77% of burn injuries develop pathological scarring. Of the patients, 44% suffer from hypertrophic scarring and 28% from hypertrophic scarring and contractures; contractures alone are present in 5% of patients with burns [2]. While scar hypertrophy often improves within 1 year after trauma [3], disturbing scar features

✉ Gerd G. Gauglitz  
gerd.gauglitz@med.uni-muenchen.de

<sup>1</sup> Department of Dermatology and Allergy,  
Ludwig-Maximilian-University Munich, Frauenlobstr. 9-11,  
80337 Munich, Germany

<sup>2</sup> Department of Plastic, Reconstructive, Hand, and Burn Surgery,  
Bogenhausen Academic Hospital, Munich, Germany

<sup>3</sup> Skin House, Milan, Italy

often persist and result in prolonged and intense patient suffering. Contractures can often cause debilitating functional disabilities and result in significantly decreased quality of life when left untreated. Burn scars in exposed areas, like the face, will often result in significantly decreased quality of life through problems like microstomia and ectropion as well as the immensely defacing impact on facial esthetics [4–8].

According to current guidelines for the treatment of pathological scarring, silicone gel preparations are recommended as a first-line therapy for hypertrophic burn scars, while the use of pressure garments, which are traditionally recommended as a first-line-therapy in guidelines specific to burn injury treatment, as well as onion extract-based products may be advisable too, even though data on their efficacy is not as robust [9–11].

Recently, fractional lasers, especially the fractional ablative carbon dioxide (CO<sub>2</sub>) laser, have been suggested as a novel tool for the improvement of hypertrophic scarring, including burn scars. While they are described as a second-line therapy in current guidelines [10, 11] and expert groups [12] emphasize the potential of the technology, high-grade evidence for the efficacy of the technology as well as objective detailing of the treatment effects observed in existing studies is currently largely missing.

Devising an efficacious, evidence-based paradigm for the treatment of widespread hypertrophic scars requires an in-depth analysis as well as quantification of the treatment effect of fractional CO<sub>2</sub> laser treatment.

In this pilot study, we therefore tried to elucidate whether a single session of fractional CO<sub>2</sub> laser treatment could already elicit changes in regards to scar severity. Employing a standardized treatment approach and an in-patient controlled study setup, we tried to quantify the effects of the laser treatment so as to lay a foundation for its application in future treatment algorithms.

## Methods

### Study algorithm

The aim of the study was to characterize the effects of a single-treatment session of fractional ablative CO<sub>2</sub> laser treatment on burn scars and to compare the effects to an untreated control area in the same patient. Two similarly scarred skin areas of roughly 10 × 10 cm were defined, one of which was to be treated and one of which was to be left untreated as the internal control.

Patient concern with the scarring, quality of life issues, and treatment progress were analyzed by employing a variety of well-established clinical questionnaires (Patient and Observer Scar Assessment Scale, Vancouver Scar Scale, Dermatology Life Quality Index). For more detailed evaluation of the

treatment progress and documentation of the controlled approach, modern clinical instruments for the purpose of analyzing skin relief and pliability were used.

Measurements of the treated and untreated scars were taken once before treatment, 1 month after, 3 months after, and 6 months after treatment. Questionnaires were completed in the same intervals.

### Patients

Ten patients (three male, seven female) with widespread hypertrophic scarring older than 1.5 years were included in the study. Their average age was 39.3 ± 15.3 years; the mean scar age was 12.45 ± 17.18 years with the freshest scars being 2.5 and the oldest 56 years old. Sixty percent of patients had already undergone other forms of scar therapy before inclusion into the study, among them scar gels and sheets, microneedling, massages, pressure garments, intralesional triamcinolone acetonide injections, and surgery. Only massages and silicone products, however, had previously been used on the scar areas treated in this study. Fitzpatrick skin types ranged between II and IV.

### Fractional CO<sub>2</sub> laser treatment

Ablative lasers, like the CO<sub>2</sub> laser, have long been an oft-used instrument in many different surgical fields and proven their potential and safety through years of clinical use. Newer models now offer fractional ablation by dividing the laser beam into many smaller beams. This leaves intact skin islets between the so-called microthermal treatment zones (MTZs), resulting in improved recovery times while retaining their known efficacy. Fractional photothermolysis could be shown to have positive effects on the concentration of tissue remodeling markers favorable for physiological wound healing, as well as producing collagen-subtype concentrations resembling those of unwounded skin [13–15].

For the laser treatment, the scar area selected for treatment was anesthetized by applying Pliaglis (70 mg/g Lidocain + 70 mg/g Tetracain, Galderma, Germany) and intake of 1 g of paracetamol 1 h before treatment. Scars were then treated using the Ultrapulse Encore® laser (Lumenis Ltd., Yokneam, Israel). The treatment was divided into three stages employing three different sets of settings. During the first stage, the ScaarFX mode was used for deep fractional ablation, so as to induce collagen remodeling in the dermis. Scars were treated with one pass of the following settings: ScaarFX, shape 2, size 10, pulse 1, density 1%, repeat delay 0.3 s, and rate 250 Hz. The micropulse energy was chosen individually for each patient, depending on the skin thickness. Once the required energy level has been reached, a contraction of the skin will be visible. During this study, the average required energy ranged between 70 and 120 mJ. During the second stage, we would superficially ablate

fine individual scar strands so as to flatten the scar relief. For this, the CPG handpiece was used with the following settings: ActiveFX, energy 40 mJ, rate 350 Hz, pattern 1, size 2, density 9, and repeat delay 0.1 s. Lastly, we would then superficially ablate the overall scar surface to ensure general smoothening. For this, we used the following settings: ActiveFX, energy 100 mJ, rate 125 Hz, pattern 1, size 6, density 2, and repeat delay 0.1 s.

Postoperatively, the wounds were treated with a fusidic acid containing salve and covered with paraffin gauze, sterile gauze, and dressings. Wounds were usually dry after 24 h and required no further dressing. Light swelling and moderate postoperative pain were treated with local cooling (e.g., through the use of ice packs). Complete healing of the wounds was usually achieved after 2 weeks. Patients were instructed to avoid direct sunlight exposure for up to 6 months after treatment. Apart from slight weeping, crusting, swelling, and postoperative erythema, no side effects were reported during the study.

To prevent infection of the treated skin, patients were prescribed cefuroxime (500 mg, twice daily) and aciclovir (400 mg, thrice daily) for oral intake for 5 days, starting 2 days before the planned treatment session.

## Documentation

### *PRIMOS<sup>pico</sup>*

The PRIMOS<sup>pico</sup> by GFMeStechnik (Teltow, Germany) is a noninvasive high-resolution imaging system that creates a three-dimensional model of the captured surface and allows for the measurement of surface irregularities. While initially designed to document wrinkles [16, 17], the PRIMOS system has since been used to successfully document different types of scarring including acne scars and keloids [18–21].

In this study, the PRIMOS<sup>pico</sup> was used to take pictures of the treated and the untreated scar areas at baseline, 1 month after treatment, 3 months after treatment, and 6 months after treatment. The PRIMOS software was then used to measure the skin roughness parameters  $S_{\max}$  (maximum profile height) and  $S_z$  (mean of the difference between the five highest and five lowest profile points) as an indicator for skin smoothness. Care was taken to ensure image capture in the same position during all examinations which was aided by the PRIMOS<sup>pico</sup>'s ability to project previously captured images onto the skin to achieve a perfect overlap with subsequent captures.

### *Courage + Khazaka Cutometer dual MPA580*

Skin toughness and elasticity measurements were performed using the Cutometer Dual MPA580 (Courage + Khazaka, Cologne, Germany). As a suction-based measurement unit, a measuring probe is placed on the patient's skin and suction is applied. After a preconfigured amount of time, the negative

pressure is released. The Cutometer optically assesses the way the skin surface travels inside an opening of the measuring probe and allows for the calculation of different parameters describing the measured skin's properties. The parameters used in this study were

$R_0$ : The maximum amplitude of the skin under negative pressure in millimeters. This parameter directly reflects the skin toughness, as tougher skin allows for less travel when negative pressure is applied and soft skin allows for more.

$R_2$ : The ratio between the maximum retraction of the skin upon release of the negative pressure and  $R_0$ . The more elastic a substance is, the higher the ratio of this parameter is, as an elastic substance is more likely to completely regain its original form after the release of the negative pressure.

As a noninvasive and accurate tool for the analysis of skin properties, the Cutometer has been used in different studies on the biomechanics of human skin and it has also been applied for the examination of burnt skin [22–25].

In this study, both the treated and untreated scar areas were analyzed during every evaluation. Since the opening of the measurement probe is extremely small (2 mm in diameter) and continuous placement in the same position over multiple dates is nearly impossible, three measurements spread out over the whole scar area were performed to avoid inaccurate description of the skin properties as well as measuring extreme values. In line with recommendations from the manufacturer, measuring mode 1 with the standard adjustments (pressure 450 mbar, on-time 5 s, off-time 3 s, repetitions 3) was used throughout the study.

### *Digital photography and VECTRA X3*

For general documentation of the studies scar areas, digital photographs were taken using a professional in-house photographer, as well as the FotoFinder® (FotoFinder Systems GmbH, Bad Birnbach, Germany) system for standardized photographs. Additionally, if the location of the scars allowed it, the Vectra® X3 (Canfield Scientific Inc., Fairfield, NJ) was used.

### *Patient and Observer Scar Assessment Scale*

The Patient and Observer Scar Assessment Scale (POSAS) is a very popular tool for the clinical assessment of scar parameters and was used for evaluation of the scar area designated for treatment in this study. First developed and validated for the documentation of burn scars [26], it soon became a staple in many studies and has since been used for the analysis of a variety of different scar types, where it proved a reliable outcome measure [27–31]. The observer part of the POSAS was evaluated by a single examiner throughout the study.

### Vancouver Scar Scale

The Vancouver Scar Scale is another well-established scale for the assessment of scars and was used to document the changes in the scar area designated for treatment in this study. Despite the use of the more comprehensive POSAS, the Vancouver Scar Scale (VSS) was included in this study for its continued popularity in current research and to establish comparability to studies employing this scar scale. Devised in 1990 for the rating of burn scars [32], the use of the scale or modified versions of it has been adapted for other scar types as well [33–35]. The Vancouver Scar Scale was rated by a single examiner throughout the study.

### Dermatology Life Quality Index

The Dermatology Life Quality Index (DLQI) is a compact yet comprehensive quality of life questionnaire. It has been used successfully for the analysis of quality of life in patients with a variety of dermatological diseases and has lately been used in different studies examining scar patients [36–40].

Providing additional information on functional and psychological impairments that are not covered by the standard scar specific scales and questionnaires, it is a valuable addition to complete documentation plans in clinical and scientific approaches for scar therapy [41].

### Statistical analysis

All individual data sets were first analyzed for Gaussian distribution by employing the D'Agostino and Pearson omnibus normality test. In case of Gaussian distribution, the baseline and 6-month-after treatment data was compared using the paired *t* test. For nonparametric data, the Wilcoxon signed rank test was used instead. Since artifacts distorted some of the Cutometer measurements and single values had to be eliminated from the evaluation, a paired analysis could not be performed. Therefore, the unpaired *t* test was used for data with Gaussian distribution and the Mann-Whitney test was employed for nonparametric data.

For the comparison between the treatment and the control area, regression analysis of the individual data sets and subsequent comparison of the curves from both groups was performed to examine the data for significant differences.

The significance level was set at  $\alpha = 0.05$ . Further on, *p* values may be abbreviated as follows: ns = not significant,  $p > 0.05$ ,  $*p < 0.05$ ,  $**p < 0.01$ , and  $***p < 0.001$ .

For statistical analysis of the data, Prism GraphPad 5.0 for Windows (GraphPad Software Inc., La Jolla, CA, USA) was used.

### Results

Pain throughout the surgery was usually mild and well tolerable. Slight discomfort was only experienced during the first stage of deep fractional ablation, whereas the second and third treatment stages were usually experienced as pain free.

### PRIMOS<sup>pico</sup>

Over the course of the study, different developments for the treated and untreated scar areas could be observed. On the treated scar sites, the parameter  $S_{\max}$ , initially measured at  $5127 \pm 2978 \mu\text{m}$ , decreased continually throughout the study, reaching  $3234 \pm 971.0 \mu\text{m}$  6 months after the treatment.  $S_z$  initially amounted to  $4441 \pm 2816 \mu\text{m}$  and ultimately fell to  $2826 \pm 983.9 \mu\text{m}$ . Both the 36.92% decrease for  $S_{\max}$  and the 36.37% drop for  $S_z$  were statistically significant (Fig. 1).

In the untreated scar areas, both  $S_{\max}$  and  $S_z$  did not show significant changes (Table 1).

However, even though an improvement of the scar relief in the treated areas was both visible (Fig. 2) and evident in the individual data set of the treated scars, comparisons between the treated and untreated scars showed no statistical differences between for both  $S_{\max}$  ( $p = 0.08655$ ) and  $S_z$  ( $p = 0.1800$ ).

### Cutometer

The development of skin firmness ( $R_0$ ) and gross elasticity ( $R_2$ ) showed different results (Table 2).

$R_0$  showed an overall increase of 30.38% from an initial  $0.2623 \pm 0.09068$  to  $0.3420 \pm 0.1299$  mm 6 months after treatment ( $p = 0.0212$ ) for the treated scars. In the untreated controls,  $R_0$  decreased by 10.90% from  $0.2908 \pm 0.09818$  to  $0.2591 \pm 0.1301$  mm ( $p = 0.3592$ ).

$R_2$  decreased by 5.030% ( $p = 0.0696$ ) in treated scars and 0.960% ( $p = 0.8296$ ) in untreated scars.

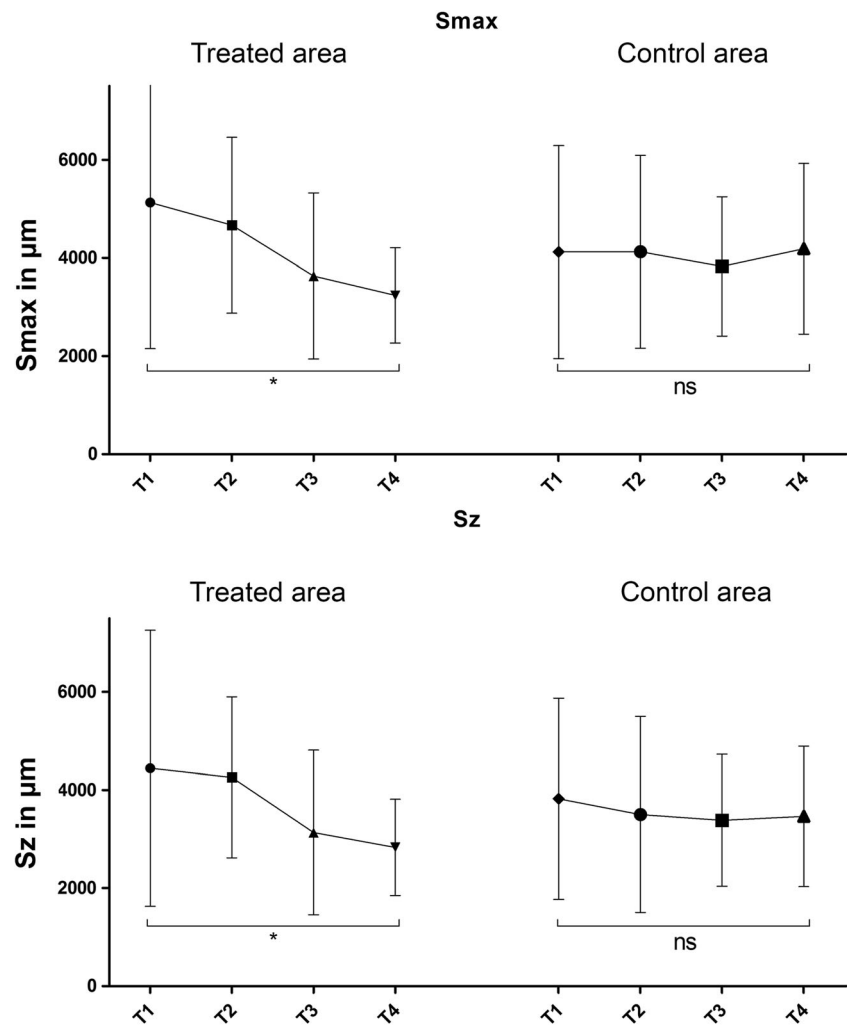
When comparing the results of both the treated and untreated scars, the differences in  $R_0$  were distinctly significant ( $p = 0.006841$ ), while no statistical differences between the groups could be discerned for the development of  $R_2$  ( $p = 0.4039$ ).

### Questionnaires

Over the course of the study, a 47.2% drop ( $p = 0.0030$ ) in the DLQI score from an initial  $8.900 \pm 5.990$  to  $4.700 \pm 3.335$  6 months after treatment could be observed.

When looking at the overall scores and their individual meaning, distinct differences between the beginning of the study and the end of it could be observed. Before receiving treatment, DLQI values indicated no influence (0–1 points)

**Fig. 1** Development of the parameters measured with the PRIMOS<sup>pic</sup> throughout the study. *P* values according to the Wilcoxon signed rank test ( $S_{\max}$  treated area,  $S_z$  treated area) and paired *t* test ( $S_{\max}$  control area,  $S_z$  control area).  $T_1$  = baseline measurement,  $T_2$  = 1 month after treatment,  $T_3$  = 3 months after treatment,  $T_4$  = 6 months after treatment. \**p* < 0.05, *ns* not significant



for one patient, a small influence (2–5 points) for two patients, a moderate influence (6–10 points) for four patients, very large influence (11–20 points) for two patients, and an extremely large influence on quality of life for one patient. Six months after treatment, the scores indicated no influence on quality of life for two patients, a small influence for four patients, and a moderate amount of influence for four patients.

The Vancouver Scar Scale showed an initial rating of  $6.800 \pm 1.317$ . Pigmentation scored  $1.200 \pm 0.6325$ , vascularity  $1.100 \pm 0.5676$ , pliability  $3.200 \pm 0.9189$ , and height  $1.300 \pm 0.6749$ . Over the course of the study, all categories showed significant drops in scoring. The overall score 6 months after treatment had dropped to  $2.200 \pm 1.549$  ( $p < 0.0001$ ), and the individual category scores ultimately

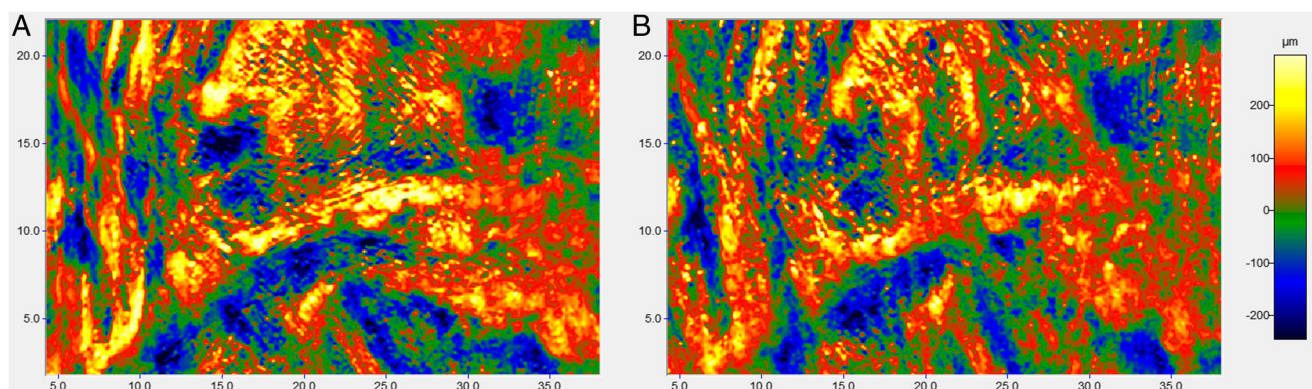
**Table 1** Results of the PRIMOS<sup>pic</sup> measurements

Device	Parameter	Area	$T_1$	$T_2$	$T_3$	$T_4$	$\Delta T_4 - T_1$ (%)	<i>p</i> Value
PRIMOS <sup>pic</sup>	$S_{\max}$ in $\mu\text{m}$	<i>T</i>	$5127 \pm 2978$	$4664 \pm 1792$	$3632 \pm 1692$	$3234 \pm 971.0$	$-1893$ (–36.92%)	0.0273
		<i>C</i>	$4117 \pm 2174$	$4122 \pm 1966$	$3824 \pm 1418$	$4184 \pm 1742$	$+67.00$ (+1.627%)	0.8788
	$S_z$ in $\mu\text{m}$	<i>T</i>	$4441 \pm 2816$	$4258 \pm 1642$	$3130 \pm 1679$	$2826 \pm 983.9$	$-1615$ (–36.37%)	0.0488
		<i>C</i>	$3817 \pm 2051$	$3499 \pm 2000$	$3382 \pm 1345$	$3459 \pm 1430$	$-385.0$ (–9.379%)	0.4125

The *p* value according to Wilcoxon signed rank test ( $S_{\max}$  (*T*),  $S_z$  (*T*)) and paired *t* test ( $S_{\max}$  (*C*),  $S_z$  (*C*))

*T* treated area, *C* control area,  $T_1$  baseline measurement at the beginning of the study,  $T_2$  1 month after treatment,  $T_3$  3 months after treatment,  $T_4$  6 months after treatment,  $\Delta T_4 - T_1$  absolute difference between the measurements at the beginning of the study and 6 months after treatment





**Fig. 2** Height map from PRIMOS<sup>pico</sup> image capture before (a) and 6 months after (b) treatment. The surface smoothing effect is visible through the reduction of profile peaks (yellow) and drops (dark blue/black)

amounted to  $0.3000 \pm 0.6749$  for pigmentation ( $p = 0.0246$ ),  $0.1000 \pm 0.3162$  for vascularity ( $p = 0.0103$ ),  $1.300 \pm 0.9487$  for pliability ( $p = 0.0004$ ), and  $0.5000 \pm 0.5270$  for height ( $p = 0.0147$ ) (Fig. 3).

The POSAS Patient Scale overall score before treatment was  $35.20 \pm 15.29$ . It declined throughout the study, eventually dropping by 26.2% to  $26.00 \pm 14.68$  6 months after treatment. The largest differences in scoring could be observed in the categories irregularity, thickness, color difference, and stiffness with score reductions of 1.900, 1.900, 1.800, and 1.700, respectively, after starting at  $7.600 \pm 3.098$ ,  $7.200 \pm 3.584$ ,  $7.500 \pm 3.100$ , and  $6.900 \pm 3.381$ . Apart from the changes in the overall score ( $p = 0.0406$ ), however, none of the changes were statistically significant. The Overall Opinion of the treated scar areas improved from  $7.500 \pm 2.506$  at baseline to  $5.700 \pm 3.368$  6 months after treatment ( $p = 0.0879$ ).

The POSAS Observer Scale showed an initial overall score of  $23.60 \pm 10.09$ , and the Overall Opinion of the scarring at the beginning of the study was rated  $5.200 \pm 2.201$ . Those scores dropped to  $13.30 \pm 2.869$  ( $p = 0.0144$ ) and  $2.600 \pm 0.8433$  ( $p = 0.0032$ ), respectively, 6 months after treatment (Fig. 4). The largest changes could be observed in the categories pliability, surface area, and thickness. Pliability was initially rated  $4.600 \pm 2.119$  and dropped to  $2.600 \pm 1.075$  at the end of the study ( $p = 0.0115$ ), surface

area fell from  $3.800 \pm 2.098$  to  $1.800 \pm 0.9189$  ( $p = 0.0129$ ), and the score for thickness decreased by 1.700 from an initial  $3.900 \pm 2.183$  ( $p = 0.0192$ ). Throughout the study, all other categories, too, showed significantly decreased scores.

## Discussion

The purpose of this pilot study was to analyze the effects of a single fractional ablative carbon dioxide laser therapy sessions on widespread hypertrophic burn scars. Within our observation period of 6 months postoperatively, significant changes in regards to objectively measured scar parameters as well as subjective patient and observer dependent evaluation were noted.

Objective clinical measurement of scar surface irregularities through the parameters  $S_{max}$  and  $S_z$  indicated significant improvement in treated scars over the course of 6 months with the most notable development occurring 1 to 3 months postoperatively. While the differences to the untreated scar areas ultimately did not hold up in statistical comparison, the ablative potential of the CO<sub>2</sub> laser remains unquestioned. While the size of the patient group might influence the statistical outcome, too, our approach to superficial scar ablation was intentionally careful. Since the deep fractional ablation during step 1 of our treatment plan, through the loosening of contractures, has considerable influence on the skin relief, too, our

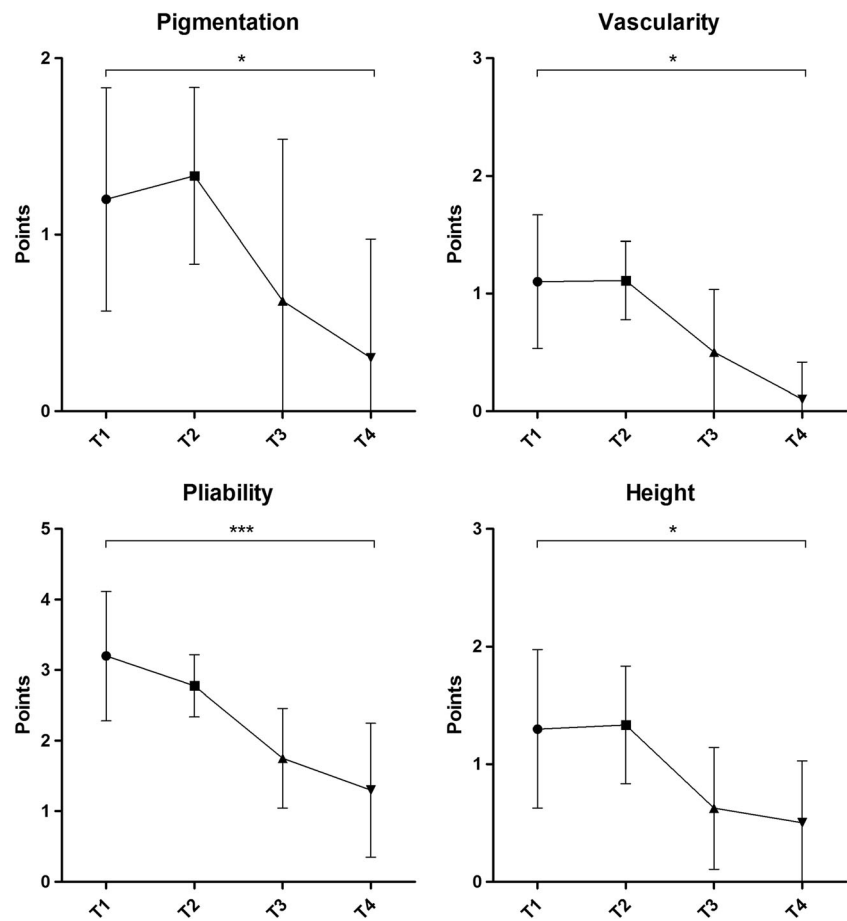
**Table 2** Results of the Cutometer measurements

Device	Parameter	Area	$T_1$	$T_2$	$T_3$	$T_4$	$\Delta T_4 - T_1$ (%)	$p$ Value
Cutometer	$R_0$ in mm	$T$	$0.2623 \pm 0.09038$	$0.2443 \pm 0.07926$	$0.2143 \pm 0.09698$	$0.3420 \pm 0.1299$	+0.0797 (+30.38%)	0.0212
		$C$	$0.2908 \pm 0.09819$	$0.2324 \pm 0.08369$	$0.2208 \pm 0.1034$	$0.2591 \pm 0.1301$	-0.0317 (-10.90%)	0.3592
	$R_2$	$T$	$0.8674 \pm 0.1869$	$0.8726 \pm 0.09292$	$0.7605 \pm 0.1271$	$0.8071 \pm 0.1699$	-5.030%	0.0696
		$C$	$0.8195 \pm 0.1662$	$0.8443 \pm 0.1253$	$0.7561 \pm 0.1800$	$0.8099 \pm 0.1401$	-0.960%	0.8258

The  $p$  value according to unpaired  $t$  test ( $R_0$  ( $T$ ),  $R_0$  ( $C$ ),  $R_2$  ( $C$ )) and Mann-Whitney test ( $R_2$  ( $T$ ))

$T$  treated area,  $C$  control area,  $T_1$  baseline measurement at the beginning of the study,  $T_2$  1 month after treatment,  $T_3$  3 months after treatment,  $T_4$  6 months after treatment,  $\Delta T_4 - T_1$  absolute difference between the measurements at the beginning of the study and 6 months after treatment

**Fig. 3** Development of the Vancouver Scar Scale categories throughout the study (treated areas). *P* values according to the Wilcoxon signed rank test (pigmentation, vascularity, height) or the paired *t* test (pliability).  $T_1$  = baseline measurement,  $T_2$  = 1 month after treatment,  $T_3$  = 3 months after treatment,  $T_4$  = 6 months after treatment. \* $p < 0.05$ , \*\*\* $p < 0.001$



goal was to avoid overcorrection of the scar relief through overzealous superficial ablation during an initial treatment session.

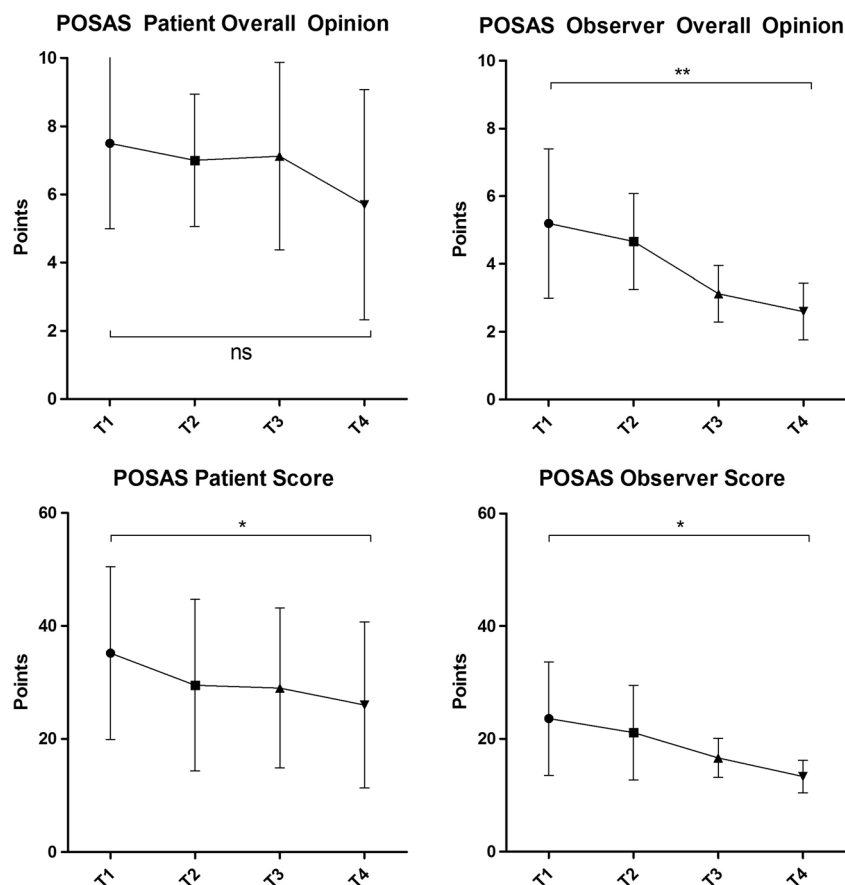
Scar firmness, too, was greatly reduced after only one treatment session. After 6 months, a reduction of 30% was visible, and though objective measuring indicated a clear development up to the last point of documentation, patients often remarked upon an improvement in skin pliability within a month after treatment. Ultimately, the improvement of scar firmness in the treated scars when compared to the untreated scars was statistically highly significant.

The comparison of before and after skin elasticity in the treated scars, however, did not yield satisfying results. However, initial measurements in both the treated and untreated scars revealed extremely high values for skin elasticity, higher even than skin elasticity values measured in healthy individuals in other studies [24]. We therefore assume that our measurements were distorted by the significant firmness of the scars. Documenting the changes in the scars, elastic properties thus require different means. While the change in elastic fiber quantity and architecture could be well analyzed with the help of skin biopsies, the ethics committee denied clearance for its use in this study.

The results of the employed questionnaires, however, all support the distinct changes to skin pliability as well as other scar parameters as a consequence of the laser treatment. Not only did the scar evaluation of the clinical examiner reveal significant improvements in both the Vancouver Scar Scale, as well as the POSAS Observer Scale, but the POSAS Patient Scale, too, showed a significant decrease, thus highlighting that the consequences of the laser treatment were also perceived by the patients and not only highly sensitive clinical measurements. This is further underlined by the significant decrease in the Dermatology Life Quality Index, representing a decreased negative influence of the scars on the patients' quality of life. While this seems unlikely, as only a small scar area was treated, patients expressed great satisfaction with having found an effective treatment method and hope for more comprehensive future treatment, thus explaining the DLQI's improvement.

Throughout the study, none of our patients experienced severe side effects after receiving laser treatment, and with the help of local topical anesthesia, treatment pain could be reduced to a well-tolerable level. Treating the designated scar areas according to our treatment protocol would usually take between 5 and 15 min. This makes the fractional ablative CO<sub>2</sub>

**Fig. 4** POSAS Patient and Observer Scale, as well as Overall Opinion development throughout the study (treated areas). *P* values according to the Wilcoxon signed rank test (POSAS Observer Score) or the paired *t* test (POSAS Patient Score, POSAS Patient Overall Opinion, POSAS Observer Overall Opinion).  $T_1$  = baseline measurement,  $T_2$  = 1 month after treatment,  $T_3$  = 3 months after treatment,  $T_4$  = 6 months after treatment. \* $p < 0.05$ , \*\* $p < 0.01$ , *ns* not significant

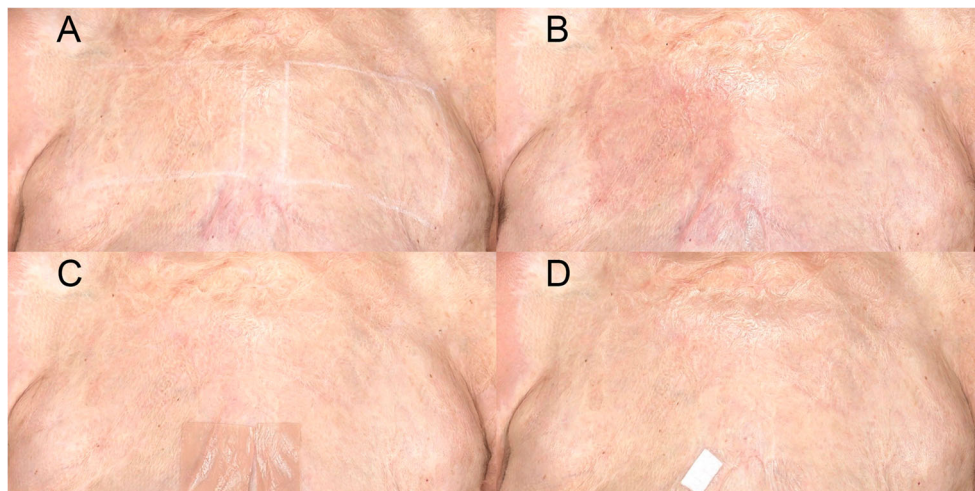


laser both a very safe as well as easily tolerable and swift treatment option, which allows for maximum patient comfort in an ambulatory setting while being able to achieve significant scar improvement with only one treatment session.

With these effects being visible after only one session, further fractional laser treatment is likely to lead to even greater improvement of the scarring. For patients under heavy strain from their severe burn scars, fractional ablative CO<sub>2</sub> laser

treatment offers an additional opportunity for scar improvement that is of particular importance when conventional surgical procedures are not available, either because the patients are unwilling to undergo further inpatient treatment or due to the lack of suitable donor sites for flaps or skin grafts. The advantage of being able to treat large (up to 400 cm<sup>2</sup>; the maximum skin surface that can be safely numbed using Pliaglis®) scar areas in an ambulatory setting with very

**Fig. 5** Vectra X3 photographic documentation of the treated (*left square*) and untreated (*right square*) scar areas before treatment (**a**), 1 (**b**), 3 (**c**), and 6 months after treatment (**d**). Though some effects of the treatment are visible (remaining erythema 1 month after treatment), an estimation of the treatment effect based on standard digital photography or similar means (Vectra X3) is hardly possible. **a** shows the outlines of the scar areas designated for treatment (*left*) and control (*right*)





limited discomfort for the patient makes this a welcome treatment option, especially in patients traumatized by long prior hospital stays and with an extensive history of surgeries. Being able to significantly improve the quality of life is of immense value for these patients who are constantly burdened by the stigma arising from their scarring and who continue to suffer from the burn trauma, long after it occurred.

Current studies have already indicated the potential of the fractional CO<sub>2</sub> laser; however, a detailed description of its clinical effects based upon a standardized treatment approach and a controlled study design has thus largely been missing, thus resulting in a low level of evidence. This study is based on both a controlled design as well as a standardized treatment approach, which ensures optimum evaluation of the treatment results as well as comparability between the individual treated patients. A larger patient collective, however, would have been desirable, as would have been the inclusion of skin biopsies to further understand the effects on skin architecture. Overall, though, we employed up-to-date methodology, technical measurement options that capture a level of detail beyond the capabilities of digital photography (Fig. 5), as well as questionnaires to ensure a most comprehensive and detailed evaluation of the treatment effect.

Future studies will now have to elucidate how to implement the results of this study and design a treatment protocol to effectively treat hypertrophic burn scars. Our results indicate the necessity of more than one session for a successful improvement of scar relief, while future research will show how far scar firmness and elasticity can be improved further and how many treatment sessions will be necessary. Naturally, both the thickness as well as the location of the scars will greatly influence the required treatment approach.

## Conclusion

Fractional ablative carbon dioxide laser treatment is a safe, swift, and highly effective option for the improvement of widespread hypertrophic burn scars. Implementing the results of this study into standardized treatment protocols is necessary to help tens of thousands of burn patients that suffer from severe functional disabilities, quality of life impairments, and debilitating esthetic disfigurement.

## Compliance with ethical standards

**Conflict of interest** Gerd G. Gauglitz serves as speaker and advisor for Lumenis. All other authors declare no conflict of interest.

**Role of funding source** No outside funding was received for this study.

**Ethical approval** This study was approved by the ethics committee of the medical faculty of the Ludwig-Maximilian-University (LMU), Munich, Germany, and it complies with the standards set within the Helsinki Declaration of 1964 and its consecutive revisions.

**Informed consent** Informed consent regarding participation in the study, laser treatment, and study-related documentation was obtained from all individual participants included in the study.

## References

1. American Burn Association (2016) Burn incidence and treatment in the United States: <http://www.ameriburn.org>
2. Gangemi E, Gregori D, Berchiolla P et al (2008) Epidemiology and risk factors for pathologic scarring after burn wounds. *Arch Facial Plast Surg* 10:93–102
3. Gauglitz GG (2013) Management of keloids and hypertrophic scars: current and emerging options. *Clin Cosmet Investig Dermatol* 6:103–114
4. Clayton NA, Ward EC, Maitz PK (2015) Full thickness facial burns: outcomes following orofacial rehabilitation. *Burns : journal of the International Society for Burn Injuries*. 41:1599–1606
5. Kowalske KJ (2011) Hand burns. *Phys Med Rehabil Clin N Am* 22:249–259 vi
6. Miller T, Bhattacharya S, Zamula W, Lezotte D, Kowalske K, Herndon D et al (2013) Quality-of-life loss of people admitted to burn centers, United States. *Quality of life research : an international journal of quality of life aspects of treatment, care and rehabilitation*. 22:2293–2305
7. Park YS, Lee JW, Huh GY, Koh JH, Seo DK, Choi JK et al (2012) Algorithm for primary full-thickness skin grafting in pediatric hand burns. *Archives of plastic surgery* 39:483–488
8. Philp L, Umrav N, Cartotto R (2012) Late outcomes after grafting of the severely burned face: a quality improvement initiative. *Journal of burn care & research : official publication of the American Burn Association* 33:46–56
9. Anzarut A, Olson J, Singh P, Rowe BH, Tredget EE (2009) The effectiveness of pressure garment therapy for the prevention of abnormal scarring after burn injury: a meta-analysis. *J Plast Reconstr Aesthet Surg* 62:77–84
10. Gold MH, Berman B, Clementoni MT, Gauglitz GG, Nahai F, Murcia C (2014) Updated international clinical recommendations on scar management: part 1—evaluating the evidence. *Dermatologic surgery : official publication for American Society for Dermatologic Surgery [et al]* 40:817–824
11. Gold MH, McGuire M, Mustoe TA, Pusic A, Sachdev M, Waibel J et al (2014) Updated international clinical recommendations on scar management: part 2—algorithms for scar prevention and treatment. *Dermatologic surgery : official publication for American Society for Dermatologic Surgery [et al]* 40:825–831
12. Anderson RR, Donelan MB, Hivnor C, Greeson E, Ross EV, Shumaker PR et al (2014) Laser treatment of traumatic scars with an emphasis on ablative fractional laser resurfacing: consensus report. *JAMA dermatology*. 150:187–193
13. Dams SD, de Liefde-van Beest M, Nuijs AM, Oomens CW, Baaijens FP (2010) Pulsed heat shocks enhance procollagen type I and procollagen type III expression in human dermal fibroblasts. *Skin research and technology : official journal of International Society for Bioengineering and the Skin (ISBS) [and] International Society for Digital Imaging of Skin (ISDIS) [and] International Society for Skin Imaging (ISSI)* 16:354–364
14. Helbig D, Paasch U (2011) Molecular changes during skin aging and wound healing after fractional ablative photothermolysis. *Skin*

- research and technology : official journal of International Society for Bioengineering and the Skin (ISBS) [and] International Society for Digital Imaging of Skin (ISDIS) [and] International Society for Skin Imaging (ISSI) 17:119–128
15. Ozog DM, Liu A, Chaffins ML, Ormsby AH, Fincher EF, Chipps LK et al (2013) Evaluation of clinical results, histological architecture, and collagen expression following treatment of mature burn scars with a fractional carbon dioxide laser. *JAMA dermatology* 149:50–57
  16. Han JY, Nam GW, Lee HK, Kim MJ, Kim EJ (2015) New analysis methods for skin fine-structure via optical image and development of 3D skin CycloScan™. *Skin research and technology: official journal of International Society for Bioengineering and the Skin (ISBS) [and] International Society for Digital Imaging of Skin (ISDIS) [and] International Society for Skin Imaging (ISSI)* 21: 387–391
  17. Prager W, Steinkraus V (2010) A prospective, rater-blind, randomized comparison of the effectiveness and tolerability of Belotero (R) basic versus Restylane (R) for correction of nasolabial folds. *European journal of dermatology* : *EJD* 20:748–752
  18. Chapas AM, Brightman L, Sukal S, Hale E, Daniel D, Bernstein LJ et al (2008) Successful treatment of acneiform scarring with CO<sub>2</sub> ablative fractional resurfacing. *Lasers Surg Med* 40:381–386
  19. Friedman PM, Skover GR, Payonk G, Geronemus RG (2002) Quantitative evaluation of nonablative laser technology. *Seminars in cutaneous medicine and surgery* 21:266–273
  20. Gauglitz GG, Bureik D, Dombrowski Y, Pavicic T, Ruzicka T, Schaubert J (2012) Botulinum toxin A for the treatment of keloids. *Skin Pharmacol Physiol* 25:313–318
  21. Reinholz M, Schwaiger H, Heppt MV, Poetschke J, Tietze J, Epple A et al (2015) Comparison of two kinds of lasers in the treatment of acne scars. *Facial plastic surgery* : *FPS* 31:523–531
  22. Akhtar N, Zaman SU, Khan BA, Amir MN, Ebrahimzadeh MA (2011) Calendula extract: effects on mechanical parameters of human skin. *Acta Pol Pharm* 68:693–701
  23. Held M, Rahmanian-Schwarz A, Rothenberger J, Schiefer J, Janghorban Esfahani B, Schaller HE et al (2015) Alteration of biomechanical properties of burned skin. *Burns : journal of the International Society for Burn Injuries* 41:789–795
  24. Luebberding S, Krueger N, Kerscher M (2014) Mechanical properties of human skin in vivo: a comparative evaluation in 300 men and women. *Skin research and technology : official journal of International Society for Bioengineering and the Skin (ISBS) [and] International Society for Digital Imaging of Skin (ISDIS) [and] International Society for Skin Imaging (ISSI)* 20:127–135
  25. Ohshima H, Kinoshita S, Oyobikawa M, Futagawa M, Takiwaki H, Ishiko A et al (2013) Use of Cutometer area parameters in evaluating age-related changes in the skin elasticity of the cheek. *Skin research and technology : official journal of International Society for Bioengineering and the Skin (ISBS) [and] International Society for Digital Imaging of Skin (ISDIS) [and] International Society for Skin Imaging (ISSI)* 19:e238–e242
  26. Draaijers LJ, Tempelman FR, Botman YA, Tuinebreijer WE, Middelkoop E, Kreis RW et al (2004) The Patient and Observer Scar Assessment Scale: a reliable and feasible tool for scar evaluation. *Plast Reconstr Surg* 113:1960–1965 **discussion 1966–1967**
  27. Bianchi FA, Rocca F, Fiorini P, Berrone S (2010) Use of Patient and Observer Scar Assessment Scale for evaluation of facial scars treated with self-drying silicone gel. *The Journal of craniofacial surgery*. 21:719–723
  28. Jina H, Simcock J (2011) Median sternotomy scar assessment. *The New Zealand medical journal* 124:57–62
  29. Maher SF, Dorko L, Saliga S (2012) Linear scar reduction using silicone gel sheets in individuals with normal healing. *J Wound Care* 21(602):604–606 **608–609**
  30. van der Wal MB, Tuinebreijer WE, Bloemen MC, Verhaegen PD, Middelkoop E, van Zuijlen PP (2012) Rasch analysis of the Patient and Observer Scar Assessment Scale (POSAS) in burn scars. *Quality of life research : an international journal of quality of life aspects of treatment, care and rehabilitation* 21:13–23
  31. Vercelli S, Ferriero G, Sartorio F, Stissi V, Franchignoni F (2009) How to assess postsurgical scars: a review of outcome measures. *Disabil Rehabil* 31:2055–2063
  32. Sullivan T, Smith J, Kermod J, McIver E, Courtemanche DJ (1990) Rating the burn scar. *The Journal of burn care & rehabilitation* 11:256–260
  33. Akita S, Akino K, Yakabe A, Imaizumi T, Tanaka K, Anraku K et al (2007) Combined surgical excision and radiation therapy for keloid treatment. *The Journal of craniofacial surgery* 18:1164–1169
  34. Cassuto DA, Scramali L, Sirago P (2010) Treatment of hypertrophic scars and keloids with an LBO laser (532 nm) and silicone gel sheeting. *Journal of cosmetic and laser therapy : official publication of the European Society for Laser Dermatology* 12:32–37
  35. Cromi A, Ghezzi F, Gottardi A, Cherubino M, Uccella S, Valdatta L (2010) Cosmetic outcomes of various skin closure methods following cesarean delivery: a randomized trial. *Am J Obstet Gynecol* 203(36):e31–e38
  36. Balci DD, Inandi T, Dogramaci CA, Celik E (2009) DLQI scores in patients with keloids and hypertrophic scars: a prospective case control study. *Journal der Deutschen Dermatologischen Gesellschaft = Journal of the German Society of Dermatology* : *JDDG* 7:688–692
  37. Bock O, Schmid-Ott G, Malewski P, Mrowietz U (2006) Quality of life of patients with keloid and hypertrophic scarring. *Arch Dermatol Res* 297:433–438
  38. Cresce ND, Davis SA, Huang WW, Feldman SR (2014) The quality of life impact of acne and rosacea compared to other major medical conditions. *Journal of drugs in dermatology* : *JDD* 13:692–697
  39. Finlay AY, Khan GK (1994) Dermatology Life Quality Index (DLQI)—a simple practical measure for routine clinical use. *Clin Exp Dermatol* 19:210–216
  40. Reinholz M, Poetschke J, Schwaiger H, Epple A, Ruzicka T, Gauglitz GG (2015) The dermatology life quality index as a means to assess life quality in patients with different scar types. *J Eur Acad Dermatol Venereol* 29:2112–2119
  41. Poetschke J, Schwaiger H, Gauglitz GG (2017) Current and emerging options for documenting scars and evaluating therapeutic progress. *Dermatol Surg* 43(Suppl 1):S25–s36