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ORIGINAL ARTICLE

Scar Prevention Using Laser-Assisted Skin Healing (LASH) in Plastic Surgery

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Abstract
Background The use of lasers has been proposed for scar revision. A recent pilot clinical study demonstrated that lasers could also be used immediately after surgery to reduce the appearance of scars. The LASH (Laser-Assisted Skin Healing) technique induces a temperature elevation in the skin which modifies the wound-healing process. We report a prospective comparative clinical trial aimed at evaluating an 810-nm diode-laser system to accelerate and improve the healing process in surgical scars immediately after skin closure.
Methods Twenty-nine women and 1 man (mean age = 41.4 years; Fitzpatrick skin types I-IV) were included to evaluate the safety and performance of the laser system. The laser dose (or fluence in J/cm^2) was selected as a function of phototype and skin thickness. Each surgical incision (e.g., abdominoplasty) was divided into two parts. An 8-cm segment was treated with the laser immediately after skin closure. A separate 8-cm segment was left untreated as a control. Clinical evaluations (overall appearance ratings, comparative scar scale) of all scars were conducted at 10 days, 3 months, and 12 months by both surgeon and patients. Profilometry analysis from silicone replicas of the skin was done at 12 months. Wilcoxon signed-rank test analyses were performed.
Results Twenty-two patients were treated using a high dose (80–130 J/cm^2) and 8 patients with a low dose (<80 J/cm^2). At 12 months in the high-dose group, both surgeon and patients reported an improvement rate of the laser-treated segment over the control area of 72.73 and 59.10%, respectively. For these patients, profilometry results showed a decrease in scar height of 38.1% ($p = 0.027$) at 12 months for the laser-treated segment versus control. Three patients treated with higher doses (>115 J/cm^2) experienced superficial burns on the laser-treated segment, which resolved in about 5–7 days. For the eight patients treated at low dosage (<80 J/cm^2), there was no significant difference in the treated segment versus the control segment. No side effects were observed.
Conclusion This prospective comparative trial demonstrates that an 810-nm diode laser treatment, performed immediately after surgery, can improve the appearance of a surgical scar. The dose plays a great role in scar improvement and must be well controlled. There is interest in LASH for hypertrophic scar revision. LASH can be used to prevent and reduce scars in plastic surgery.

Keywords Wound healing · Heat shock proteins · Heat · Laser · Scar

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The cosmetic outcome of surgical scars is of paramount importance to physicians and patients undergoing surgery. Predicting the wound-healing properties of individual patients is difficult. The postsurgical wound-healing process is closely associated with various cellular activities that occur over several months [1]. Pain and itchiness are commonly reported symptoms associated with scarring

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[2, 3]. Normal wound healing of the skin results in a flat and flexible scar. However, scar tissue remains weaker than normal skin and has an altered extracellular matrix composition [4]. The ideal end point would be total regeneration, with the new tissue having the same structural, aesthetic, and functional attributes as the original uninjured skin.

Every effort must be made to improve scar appearance and, more importantly, to avoid the development of postsurgical hypertrophic scars or keloids. Excellent surgical technique and efforts to prevent postsurgical infection are of prime importance. Prevention of hypertrophic scars is obviously preferable to treatment and implies using a therapy aimed at reducing their incidence [2]. The use of lasers has already been proposed for scar revision. Er-YAG and CO_2 lasers were first proposed, particularly for atrophic, hypertrophic, and keloid scars [5, 6]. However, these ablative techniques are associated with significant downtime, prolonged erythema, and swelling, and, furthermore, they carry the potential risk of permanent hypo- or hyperpigmentation. Next, nonablative laser techniques were proposed. Pulsed dye lasers (PDL) showed encouraging results on existing hypertrophic and keloid scars [7, 8]. The PDL was proven to be a safe and effective option for improving the cosmetic appearance of surgical scars in skin types I-IV starting on the day of suture removal [9, 10]. Finally, the fractional erbium-glass laser has also been evaluated with encouraging results [3, 11].

Lasers could also be used before or immediately after surgery to prevent (or at least reduce) the apparition of scars. Capon et al. [12] showed the ability of an 810-nm diode-laser system to assist in wound closure. Acceleration of wound healing and an indiscernible scar were obtained in hairless rats. More recently, this finding was confirmed in a pilot study of five patients. Laser-treated scar portions demonstrated better quality compared with untreated scar portions [13]. Finally, a recent study reported for the first time the possibility of improving the appearance of hypertrophic scars by altering, through a controlled thermal stress, the wound-healing process immediately after conventional hypertrophic scar revision [14].

Here we report a prospective comparative clinical trial aimed at evaluating an 810-nm diode-laser system for use in accelerating and improving the healing process in surgical scars of patients with Fitzpatrick skin types I-IV immediately after skin closure.

Patients and Methods

This prospective comparative clinical trial was conducted on 30 patients to evaluate the safety and performance of an 810-nm diode-laser system (Table 1) in two different departments of surgery (Lille and Marseille). Four surgeons were involved in this clinical trial: one in Lille (AC) and three in Marseille (ND, DG, GM). Twenty-nine women and one man were included (mean age = 41.4 years). This clinical trial was approved by the Ethics Committee [Comité Consultatif de Protection des Personnes en Recherche Biomédicale (CCPPRB) de la Région Nord Pas-de-Calais, Lille, France, protocol 2006/07/023]. Patients under 18 years of age, with dark skin (skin types V or VI), pregnant women, and patients with a history of malignant tumor skin disease, bacterial or viral infectious skin disease, immunosuppression, and under long-term corticosteroids were excluded. Patients were instructed to avoid sun exposure and to use sunscreen until the end of the study. All subjects were informed of the objective of the study and gave their written informed consent.

Surgical incisions were closed in two ways: first absorbable suture and then intradermal suture or transparent dressing. Each surgical incision (e.g., abdominoplasty) was divided into two sides. One side (8 cm) was used for treatment and the other was left untreated to be used as a control (Fig. 1). Treated and untreated segments were selected randomly.

Laser irradiation was performed using a 4-mm circular spot or a rectangle (length = 20 mm, width = 4 mm). The laser beam was perpendicular to the skin surface. Only one pass was performed. Fluence ranging from 51 to 127 J/cm^2 (mean ± SD = 89.9 ± 21.2 J/cm^2) was selected as a function of phototypes.

The equipment used for the study was an 810-nm Ceralas laser (CERAMOPTEC, Germany, used in Lille) or 810-nm Diolas laser (ECHOLAS, France, used in Marseille). The wavelength was 810 nm and power up to 20 W. A 400-μm pure silica fiber optic was connected to the laser system (ref. LPC-04-980-400/440-QM-2-4, 5AS-35-5-3A-3; OZ Optics, Canada). All devices were approved for medical use.

Clinical evaluations of all scars were conducted at 10 days, 3 months, and 12 months. A comparative scar evaluation based on cosmetic appearance using a visual analog scale from −100 (worst) to 100 (best) was performed by both surgeon and patients (Fig. 2). The improvement rate was determined using the visual analog scale (e.g., a patient scoring +60% meant an improvement of 60% for the laser-treated scar segment over the control side; a patient scoring −40% meant a deterioration of 40% for the laser-treated scar segment over the control side). Overall appearance ratings ranging from an optimum of 0 to a minimum of 3 (0 = excellent, 1 = good, 2 = fair, 3 = poor) were also assigned to each segment at each time point. Finally, subjective evaluations of the scars (modified

Table 1 Patients' characteristics

Patient	Age	Sex	Skin type	Location	Fluence (J/cm^2)	Superficial burn	Silicone imprints
1	35	F	III	Breast	93	–	–
2	47	F	II	Abdomen	104	–	–
3	48	F	II	Abdomen	87	–	Yes
4[a]	49	F	III	Abdomen	116	Yes	–
5	53	F	II	Abdomen	87	–	–
6	51	F	II	Abdomen	99	–	–
7	49	F	III	Abdomen	77	–	–
8	32	F	II	Abdomen	51	–	–
9	36	F	II	Abdomen	51	–	–
10	33	M	II	Abdomen	58	–	–
11	26	F	II	Abdomen	58	–	–
12	43	F	II	Abdomen	58	–	–
13	54	F	I	Abdomen	73	–	–
14	41	F	III	Abdomen	112	–	–
15	33	F	III	Abdomen	112	–	–
16	47	F	II	Abdomen	112	–	–
17	43	F	II	Abdomen	112	–	–
18	54	F	III	Abdomen	94	–	Yes
19	46	F	II	Abdomen	89	–	Yes
20	39	F	II	Abdomen	89	–	–
21	49	F	II	Abdomen	87	–	–
22	29	F	II	Abdomen	87	–	Yes
23	27	F	III	Abdomen	86	–	Yes
24	34	F	III	Abdomen	99	–	–
25[a]	37	F	I	Abdomen	127	Yes	–
26[a]	39	F	III	Abdomen	127	Yes	–
27	39	F	I	Abdomen	99	–	–
28	53	F	IV	Abdomen	99	–	Yes
29	40	F	III	Abdomen	91	–	–
30	37	F	IV	Abdomen	66	–	–

[a] Patients with superficial burns on the treated portion, resolved in the 5–7 days

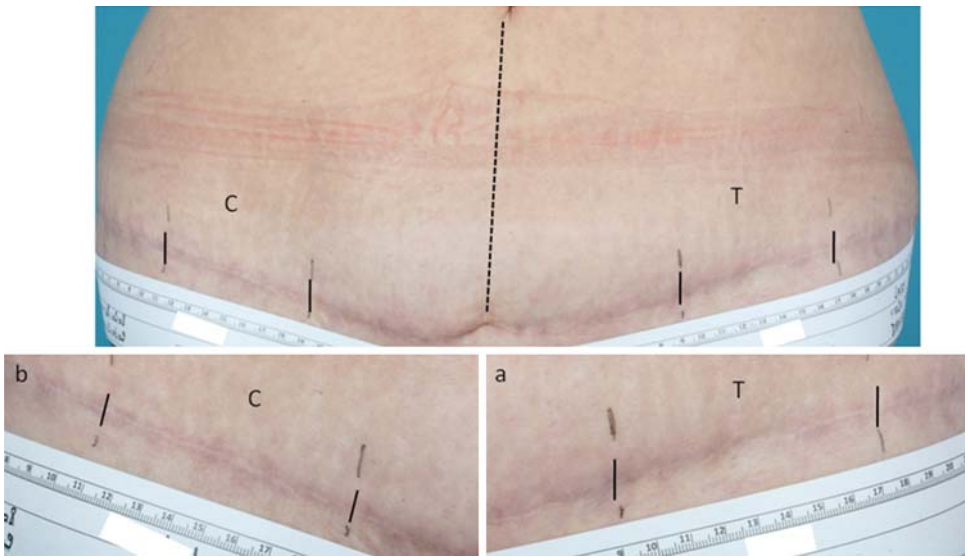

Fig. 1 Patient No. 17 at 12 months, fluence = 111 J/cm^2. **a** Treated portion (*right side*). **b** Control portion (*left side*)

Laser Treated Scar Segment	□	□	□	□	□	□	□	□	□	□	□	Control Scar Segment
	100%	80%	60%	40%	20%	0%	-20%	-40%	-60%	-80%	-100%	

(0% means no difference between laser and control part)

Fig. 2 Visual analog scale used for scar assessment. +60% means an improvement of 60% for the laser-treated scar segment over the control scar segment; −40% means a deterioration of 40% for the laser-treated scar segment over the control scar segment

VQ-Dermato and Body Image Scale) were performed at 30 days: "During the last 4 weeks, did the treated portion cause less itching, burning, prickling, or any other type of pain?"

Profilometry analysis of skin silicone rubber replicas (SIFLO®, Monaderm, Monaco) was performed using the Dermatop® 3D scanner (Eotech, France). This scanner is specially optimized for dermatological and cosmetic applications to obtain accurate noncontact measurement and examine human skin topography. Replicas of the control and treated scars of each patient were made and then scanned using the Dermatop system to give a rectangular (20 mm × 10 mm) topographical zone of.

The SPSS v16.0 software package (SPSS Inc., Chicago, IL) was used for statistical analysis. Mean values and standard deviations were calculated. For comparisons between groups, the Wilcoxon test was used. Values of $p < 0.05$ were accepted as statistically significant.

Results

Twenty-two patients were treated with high doses (80–130 J/cm^2) and 8 patients with low doses (<80 J/cm^2) of laser. Patients' characteristics are reported in Table 1.

All Cases

No significant complications occurred during the course of this study.

Twenty of 30 subjects had an improvement in the quality and visual aspect of their treated scar at final scar analysis (12 months). In all cases (30), improvement rates for surgeon and patients were 60 and 53.4%, respectively, for the laser-treated scar segment compared with the control scar segment (Table 2). The laser-treated portion scored significantly higher for both surgeon (0.53 ± 0.63 vs. 0.83 ± 0.53, $p = 0.020$) and patients (0.50 ± 0.51 vs. 0.87 ± 0.57, $p = 0.005$) when compared with the control side using the Wilcoxon signed-rank test. Patients noticed less discomfort (itching, burning, and prickling) in the treated scar segment for the first 30 days after surgery.

High Doses (fluence >80 J/cm^2)

Three patients (Nos. 4, 25, and 26) (Table 3) experienced superficial burns on the laser-treated segment of the scar due to a higher dose (116, 127, and 127 J/cm^2, respectively), which resolved in about 5–7 days. No residual pigmentation or scarring from the burn was observed.

In the high-doses cases, the surgeon assessed a greater improvement rate for the laser-treated portion compared to the control part at the 12-month follow-up. The treated portion was scored significantly better by the surgeon (0.50 ± 0.60 vs. 0.9 ± 0.47, $p = 0.02$) and the patients (0.50 ± 0.51 vs. 1.0 ± 0.58, $p = 0.008$) than the control side. Similarly, surgeon and patients reported an improvement rate of 72.73 and 59.10%, respectively.

Low Dose (fluence <80 J/cm^2)

For low-dose-treated patients (<80 J/cm^2) there was no significant difference in the treated portion compared with the control portion (surgeon: 0.75 ± 0.71 vs. 0.75 ± 0.71, n.s.; patient: 0.53 ± 0.53 vs. 0.63 ± 0.52, n.s.). The surgeon scored the laser and control parts similarly (25%) (Table 4).

Finally, using the comparative scar evaluation, the surgeon scored the high-dose-treated portion better than the low-dose-treated portion ($p = 0.034$), as did the patients ($p = 0.026$).

Profilometry Analysis

Profilometry data came from six patients treated at high doses (Nos. 3, 18, 19, 22, 23, and 28). The decrease in scar height was 130, 32, 27, 38, 47, and 47 μm, respectively (Figs. 3, 4, 5), becoming 38.1% ($p = 0.027$) at 12 months for the laser-treated scar segment vs. control.

Discussion

In this study, an 810-nm diode-laser system was used to treat fresh surgical scars on 30 patients in a single pass

Table 2 Comparative scar assessment estimated by surgeon and patient at 12 months

Patient	Surgeon			Patient		
	Laser-treated scar segment	Control scar segment	Comparative scar evaluation (%)	Laser-treated scar segment	Control scar segment	Comparative scar evaluation (%)
1	0	1	80	0	1	80
2	0	1	80	1	2	100
3	0	1	60	0	1	80
4[a]	0	1	40	0	1	60
5	1	1	40	1	1	60
6	1	1	0	0	0	0
7	1	1	0	1	1	0
8	1	1	20	0	1	80
9	0	0	0	0	0	0
10	1	1	0	1	1	20
11	1	1	0	1	1	0
12	0	0	0	0	0	0
13	2	2	0	1	1	0
14	1	1	−20	1	1	0
15	0	1	60	0	1	80
16	0	0	20	1	0	−20
17	0	1	40	1	1	0
18	1	1	0	1	1	0
19	0	0	0	0	0	0
20	0	1	60	1	2	60
21	2	0	−40	1	1	0
22	1	1	0	1	1	20
23	0	0	20	1	1	60
24	0	1	40	0	1	80
25[a]	0	1	80	0	0	0
26[a]	0	1	100	0	1	100
27	1	1	40	1	1	40
28	1	1	40	0	1	100
29	1	2	60	0	2	80
30	0	0	40	0	0	0
Mean	0.53 ± 0.63	0.83 ± 0.53	–	0.50 ± 0.51	0.87 ± 0.57	–
Rate			60.0%[b]			53.4%[b]

Subjective evaluations of the scars were performed at 30 days: "During the last 4 weeks, did the treated portion cause less itching, burning, prickling, or any other type of pain?" Overall appearance ratings ranging from an optimum of 0 to a minimum of 3 (0 = excellent, 1 = good, 2 = fair, 3 = poor) were assigned to each segment. Comparative scar evaluation at 12 months was based on cosmetic appearance using a visual analog scale from −100 (worst) to 100 (best) after one pass of laser treatment

NA not assessed

[a] Patients with superficial burns on the treated portion, resolved in the 5–7 days

[b] Comparative scar evaluation rate (>0% means scar improvement)

immediately after skin closure. A cosmetic visual analog scale from −100 (worst) to 100 (best) was used to assess the quality and appearance of surgical scars. There was no significant difference between the treated portion of the scar and the control until the 12-month follow-up. The overall scar score improved for the laser-treated scar segments compared to the control scar segments with estimated rates of improvement of 60 and 54.3% for surgeon and patients, respectively. This study showed also that the high-dose (80–130 J/cm^2) treated scar portion was scored better than the low-dose (50–80 J/cm^2) treated scar portion by both surgeon and patients. A significant improvement of the laser-treated segment compared with the control segment was also observed. Surgeons gave a

Table 3 Comparative scar assessment estimated by surgeon and patient at 12 months for high dose (fluence >80 J/cm^2)

Case	Dose	Surgeon			Patient		
		Treated portion (score/3)	Control portion (score/3)	Comparative scar evaluation (%)	Treated portion (score/3)	Control portion (score/3)	Comparative scar evaluation (%)
1	93	0	1	80	0	1	80
2	104	0	1	80	1	2	100
3	87	0	1	60	0	1	80
4[a]	116	0	1	40	0	1	60
5	87	1	1	40	1	1	60
6	99	1	1	0	0	0	0
14	112	1	1	−20	1	1	0
15	112	0	1	60	0	1	80
16	112	0	0	20	1	0	−20
17	112	0	1	40	1	1	0
18	94	1	1	0	1	1	0
19	89	0	0	0	0	0	0
20	89	0	1	60	1	2	60
21	87	2	0	−40	1	1	0
22	87	1	1	0	1	1	20
23	86	0	0	20	1	1	60
24	99	0	1	40	0	1	80
25[a]	127	0	1	80	0	0	0
26[a]	127	0	1	100	0	1	100
27	99	1	1	40	1	1	40
28	99	1	1	40	0	1	100
29	91	1	2	60	0	2	80
Mean		0.5 ± 0.6	0.9 ± 0.47	–	0.5 ± 0.51	1.0 ± 0.58	–
Rate				72.73%[b]			59.10%[b]

Overall appearance ratings ranging from an optimum of 0 to a minimum of 3 (0 = excellent, 1 = good, 2 = fair, 3 = poor) were assigned to each segment. Comparative scar evaluation at 12 months was based on cosmetic appearance using a visual analog scale from -100 (worst) to 100 (best) after one pass of laser treatment

[a] Patients with superficial burns on the treated portion, resolved in the 5–7 days

[b] Comparative scar evaluation rate (>0% means scar improvement)

score of 72.7% for the high dose compared to 25% for the low dose.

A higher dose means a higher temperature increase in the skin. Skin temperature elevation plays a major role in modifying the wound-healing process. As previously demonstrated in experimental evaluations on animals, temperature elevation results in a marked increase in levels of heat shock protein 70 (HSP70) in skin structures, particularly around blood vessels, hair follicles, and sebaceous glands [15]. Heat shock response (in particular HSP70 synthesis) is responsible for the release and production of growth factors (in particular via the modification of the TGFβ profile), thus increasing the rate of cell proliferation and the speed of collagen production, hence improving scar aspect [16, 17]. Several studies have demonstrated that the most significant difference between normal tissue and scar tissue is in the orientation of the fibrosis matrix [18, 19]. This observation may be explained by our profilometry results which showed a decrease of 38.1% of the laser-treated segment over control. However, too high a dose can lead to an excessive temperature. Three patients experienced superficial burns on the laser-treated segment of the scar from an overdose of laser energy (116, 127, and 127 J/cm^2, respectively), which resolved in about 5–7 days. This study confirms that the dose must stay below a damage threshold of around 110 J/cm^2 in our case.

The use of lasers allows a paradigm shift from passive to active prevention of hypertrophic scar formation. Using a pulsed dye laser (PDL), Nouri et al. [9] found a beneficial effect with three laser treatments of scars starting on the day of suture removal. Conologue and Norwood [10] showed a significant improvement of 60% in laser-treated scars (three treatments at 4 to 8-week intervals) with a PDL compared with controls. Alam et al. [20] observed that a

Table 4 Scar assessment estimated by surgeon and patient at 12 months for low dose (fluence <80 J/cm^2)

Case	Dose	Surgeon			Patient		
		Treated portion (score/3)	Control portion (score/3)	Comparative scar evaluation (%)	Treated portion (score/3)	Control portion (score/3)	Comparative scar evaluation (%)
7	77	1	1	0	1	1	0
8	51	1	1	20	0	1	80
9	51	0	0	0	0	0	0
10	58	1	1	0	1	1	20
11	58	1	1	0	1	1	0
12	58	0	0	0	0	0	0
13	73	2	2	0	1	1	0
30	66	0	0	40	0	0	0
Mean		0.75 ± 0.71	0.75 ± 0.71	–	0.5 ± 0.53	0.63 ± 0.52	–
Rate				25%[a]			25%[a]

Overall appearance ratings ranging from an optimum of 0 to a minimum of 3 (0 = excellent, 1 = good, 2 = fair, 3 = poor) were assigned to each segment. Comparative scar evaluation at 12 months was based on cosmetic appearance using a visual analog scale from −100 (worst) to 100 (best) after one pass of laser treatment

[a] Comparative scar evaluation rate (>0% means scar improvement)

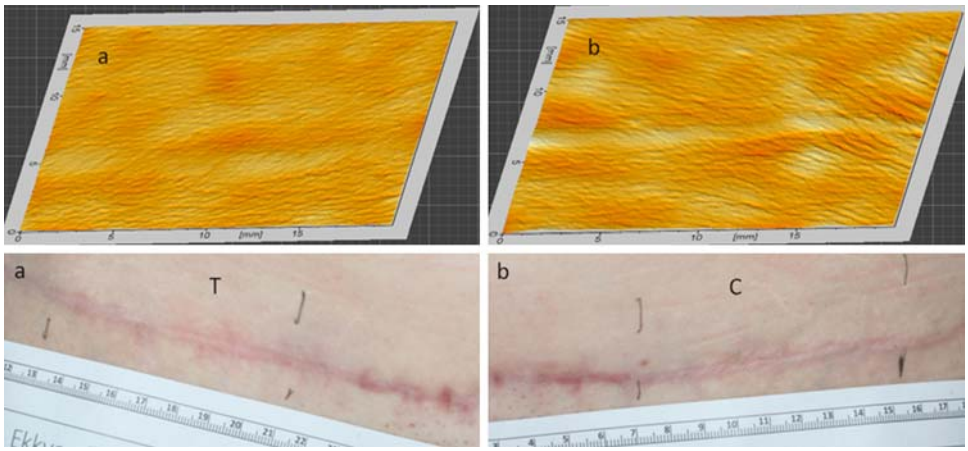

Fig. 3 Patient No. 22 at 12 months, fluence = 87 J/cm^2. **a** Treated portion (*left side*), mean height = 54 μm. **b** Control portion (*right side*), mean height = 92 μm (−41% decrease)

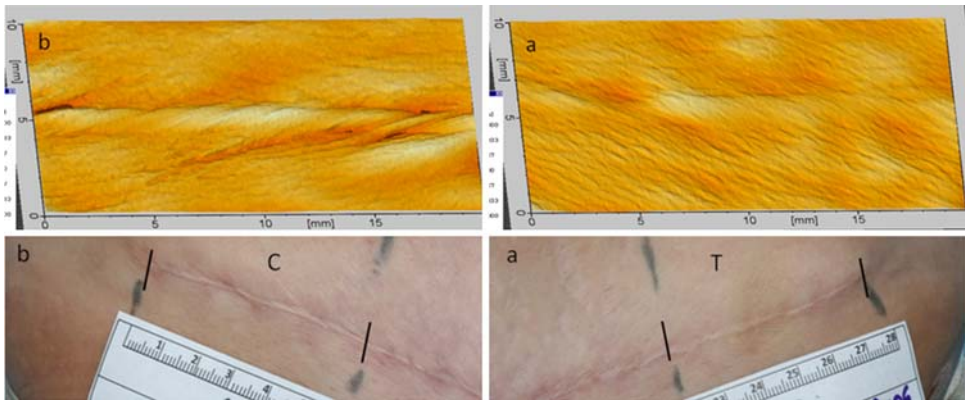

Fig. 4 Patient No. 3 at 12 months, fluence = 87 J/cm^2. **a** Treated portion (*right side*), mean height = 250 μm. **b** Control portion (*left side*), mean scar height = 120 μm (−52% decrease)

single PDL treatment at the time of suture removal did not appear to have a clinically beneficial effect on scar appearance. They suggested that the threshold for minimal benefit of such laser treatments may lie somewhere between one and three treatments. Even though the PDL demonstrates numerous positive results, its scar prevention principles remain to be clearly explained. It has been also suggested that PDL stimulates blood vessels and various growth

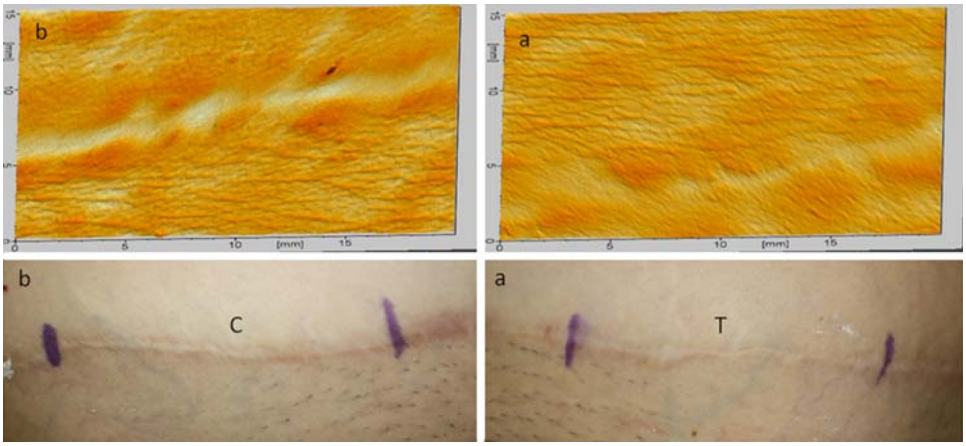

Fig. 5 Patient No. 28 at 12 months, fluence = 99 J/cm^2. **a** Treated portion (*right side*), mean height = 58 μm. **b** Control portion (*left side*), mean scar height = 105 μm (−45% decrease)

factors. Choe et al. [11] and Tierny et al. [3] found that a nonablative fractional laser could have scar-preventive benefits similar to those achieved with PDL, particularly from the temperature elevation induced inside the dermis.

Conclusion

This prospective comparative trial demonstrates that an 810-nm diode-laser treatment performed immediately after surgery can improve the appearance of a surgical scar. This study demonstrates also that an optimal dose is required. Further studies may be warranted to optimize 810-nm diode-laser parameters for scar revision, reduction, and prevention and to understand the cellular mechanisms leading to laser-induced wound healing. LASH (Laser-Assisted Skin Healing) should certainly be utilized to improve the appearance of both hypertrophic and keloid scars.

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