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Treatment of Resistant Tattoos Using a New Generation Q-Switched Nd:YAG Laser: Influence of Beam Profile and Spot Size on Clearance Success

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Background and Objectives: Multiple treatments of resistant tattoos often result in fibrosis and visible textural changes that lessen response to subsequent treatments. The aim of this study is to evaluate the influence of beam profile and spot size on clearance rates and side effects in the setting of resistant tattoos.
Study Design/Material and Methods: Thirty-six professional, black tattoos (32 patients) were treated unsuccessfully with a Q-switched Nd:YAG laser (MedLite^{TM} C3, HoyaConBio Inc., Fremont, CA). Because of therapy resistance all tattoos were re-treated using a new generation Nd:YAG laser (MedLite^{TM} C6, HoyaConBio Inc.). Maximum energy fluence (E_{max}), mean energy fluence, mean spot size, level of clearance, side effects and beam profile (irradiance distribution) of both laser systems were assessed and evaluated in a retrospective study.
Results: All tattoos were previously treated with the C3 laser at 1,064 nm using a mean E_{max} of 5.8 ± 0.8 J/cm^2 (range 3.8–7.5 J/cm^2) as compared with a mean E_{max} of 6.4 ± 1.6 J/cm^2 (range 3.2–9.0 J/cm^2) during the C6 treatment course. Corresponding spot sizes were larger during C6 treatments as compared with C3 (5.0 ± 0.9 and 3.6 ± 0.2 mm, respectively). The C6 laser had a "flat top" and homogenous profile regardless of the spot size. For the C3 laser the beam shape was "Gaussian," and the homogeneity was reduced by numerous micro-spikes and micro-nadirs.
After the C6 treatment course 33.3% of the tattoos showed clearance of grade 1 (0–25%), 16.7% of grade 2 (26–50%), 16.7% of grade 3 (51–75%), 30.5% of grade 4 (76–95%), 2.8% of grade 5 (96–100%). The total rate of side effects due to C6 treatment was 8.3% in all tattoos (hyperpigmentation 5.6%, hypopigmentation 2.7%, textural changes/scars 0%).
Conclusion: This clinical study documents for the first time the impact of a 1,064-nm Nd:YAG laser with a more homogenous beam profile and a larger spot size on the management of resistant tattoos. Only a few treatment sessions were necessary to achieve an additional clearance with a low rate of side effects. Lasers Surg. Med. 40:139–145, 2008. © 2008 Wiley-Liss, Inc.

Key words: image analysis; irradiance distribution; neodymium:yttrium–aluminum–garnet laser; skin tattoos; tattoo removal

INTRODUCTION

Despite the implementation of Q-switched lasers, clinicians are still confronted with the problem of resistant tattoos. The appropriate combination of the three parameters of wavelength, pulse duration and energy per unit area (J/cm^2) has been shown to be pivotal for successful selective pigment destruction [1]. It has also become apparent that other parameters, particularly spot size and beam profile, may contribute to the ultimate treatment outcome [2–4]. None of these parameters, however, have been clinically evaluated in the setting of resistant tattoos. On the other hand, improvements in laser design have led to better beam profiles and higher peak powers enabling larger spot sizes. For this reason, we decided to analyze the influence of spot size and beam profile on the clearance success and the rate of side effects of resistant black tattoos in a retrospective study.

MATERIALS AND METHODS

Laser Systems

Before our patients were recruited, they had previously been treated with a Q-switched 1,064-nm Nd:YAG laser system (MedLite^{TM} C3, HoyaConBio Inc.). Because of therapy resistance the tattoos were re-treated with a new generation Q-switched 1,064-nm Nd:YAG laser system (MedLite^{TM} C6, HoyaConBio Inc.). For technical data, see Table 1.

Subjects

This retrospective trial included 32 patients (14 males, 18 females; age 35.8 ± 9.6 years, range 21.4–73.2) who were re-treated between September 2005 and December 2006 for

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There is no conflict of interest. None of the authors of the study has financial interest of any kind or is in any way related to manufacturers, wholesalers or retailers of one of the laser systems under investigation.

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TABLE 1. Comparison of Technical Data of Both Laser Systems Under Investigation

Laser	Energy per pulse (mJ)	Spot size (mm)	E_{max} at 1,064 nm (J/cm^2)	Pulse duration (ns)	Pulse frequency (Hz)
C3	450	2	14.3	8–10	1–10[a]
		3	6.4		
		4	3.6		
C6	1,000	3	14.2	8–10	1–10[a]
		4	8.0		
		6	3.5		
		8	2.0		

[a] The pulse frequency used in this trial was 10 Hz.

removal of 36 professional, black tattoos using a new generation Nd:YAG laser (C6). Patients were enrolled on a consecutive basis as long as their tattoos were considered to be Nd:YAG (C3)-resistant (i.e., had undergone at least 12 treatments and had three consecutive treatments with minimal tattoo ink lightening). The time period between previous (C3) and current (C6) tattoo treatments was set at 3 months in order to avoid a confounding influence of the final C3 treatment session on the study results. The C6-based tattoo removal therapy is still ongoing, but the preliminary results are reported here.

Beam Profile Analyzer

The beam profiles were determined by imaging the beam with a charge-coupled device camera (TCamD20/15 CCD Camera, DataRay Inc., Boulder Creek, CA). The laser beams were attenuated by absorptive neutral-density filters in order to avoid damage to the CCD camera. The CCD camera was placed at the end of the MultiSpot Handpiece^{TM} (HoyaConBio Inc.) to monitor the same beam profiles on patients' skin. The digital video signal was fed into the USB port of a personal computer. After capturing the beam profile image, the spatial intensity of the beam and the spatial distribution in two or three dimensions were determined by using a DataRay Analyzer (Version 5.00 M4) provided by HoyaConBio Inc. These data were analyzed off-line, and graphic representations of beam spot homogeneity were quantified as a percentage of variation along the profile.

Calculation of "Mean Energy," "Mean E_{max}," and "Mean Spot Size"

We developed specific parameters in order to describe the energy and spot size applied to the tattoos. For each patient all data of energy density and spot size collected at each treatment session were summed up and divided by the total number of treatment sessions. The results were defined as the "mean energy fluence" (J/cm^2) and "mean spot size" (mm). We also identified the highest fluence applied in a single treatment session and the corresponding spot size. These energy data of all 36 tattoos were summed up and divided by the number of tattoos, and the result was defined

TABLE 2. Localization of Tattoos, Age of Patients, Number of Treatments, Maximum Energy Fluence (E_{max}), Mean Energy Fluence and Spot Size of C3 and C6 Treatments

Localization of tattoos	$n = 36$ tattoos
Upper arm	12 (33.3%)
Forearm	8 (22.2%)
Trunk	12 (33.3%)
Lower leg	4 (11.2%)
Age of patients (years)	$n = 32$ patients
Mean ± SD	35.8 ± 9.6
Median	35.1
Range	21.4–73.2
No. of C3 laser pre-treatments	
Mean ± SD	18.6 ± 8.0
Median	16.0
Range	12–37
Energy data of C3 laser pre-treatments (J/cm^2)	
Mean ± SD	3.8 ± 0.5
Median	3.9
Range	2.6–7.5
E_{max} of C3 laser pre-treatments (J/cm^2)	
Mean ± SD	5.8 ± 0.8
Median	5.8
Range	3.8–7.5
Spot size of C3 laser pre-treatments (mm)	
Mean ± SD	3.6 ± 0.2
Median	3.6
Range	3.2–3.9
No. of C6 laser treatments	$n = 5.0$
Energy data of C6 laser treatments (J/cm^2)	
Mean ± SD	4.8 ± 1.3
Median	4.7
Range	2.2–8.2
E_{max} of C6 laser treatments (J/cm^2)	
Mean ± SD	6.4 ± 1.6
Median	6.2
Range	3.2–9.0
Spot size of C6 laser treatments (mm)	
Mean ± SD	5.0 ± 0.9
Median	4.8
Range	3.6–7.6

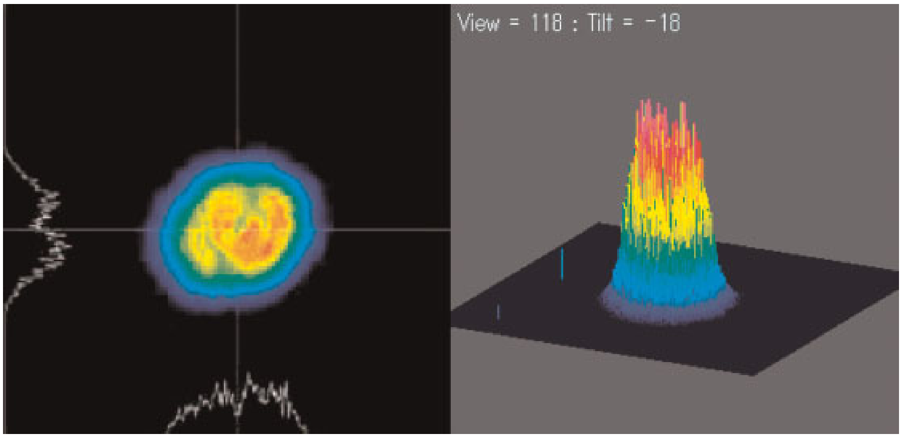

Fig. 1. 3D-beam profile of the C3 laser (wavelength 1,064 nm, spot size 4 mm, energy per pulse 450 mJ/cm^2, pulse duration 8–10 ns, pulse frequency 10 Hz) produced by DataRay v.500M4 software. This is the typical "Gaussian" profile. [Figure can be viewed in color online via www.interscience.wiley.com.]

as "mean E_{max}." The mean energy fluence describes the average energy applied to the tattoo of each patient, the mean spot size describes the average area to which this energy was applied, and mean E_{max} is the average maximum energy applied during the total therapeutic course.

Technique

All tattoos had been treated with the C3 laser at 1,064 nm using a mean E_{max} of 5.8 ± 0.8 J/cm^2 (median 5.8 J/cm^2, range 3.8–7.5 J/cm^2) at a mean spot size of 3.6 ± 0.2 mm (range 3.2–3.9 mm). During C6 treatments, we applied a mean E_{max} of 6.4 ± 1.6 J/cm^2 (median 6.2 J/cm^2, range 3.2–9.0 J/cm^2) at a mean spot size of 5.0 ± 0.9 mm (range 3.6–7.6 mm).

Each tattoo was treated five times at 4-week intervals. Whitening and pin point bleeding of the tissue were employed as visual markers of therapeutic effect. Upon completion of each treatment session, a Sulfadiazin-cream-bandage (Flammazine® cream, Emra-Med Arzneimittel Inc., Trittau, Germany) was applied.

Clinical Assessment

The clinical evaluation included site and color of each tattoo. Photographs were taken with the same 60-mm camera (EOS 350 D, Canon Inc.) under standardized

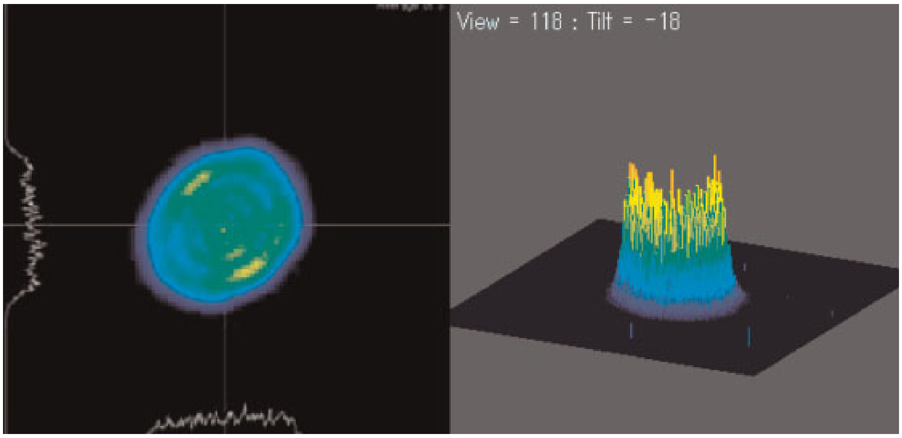

Fig. 2. 3D-beam profile of the C6 laser (wavelength 1,064 nm, spot size 4 mm, energy per pulse 1,000 mJ/cm^2, pulse duration 8–10 ns, pulse frequency 10 Hz) produced by DataRay v.500M4 software. The distribution of the energy density is more homogenous as compared with C3. The C6 beam has a flat top and most of the area is equal to the average of the energy applied. [Figure can be viewed in color online via www.interscience.wiley.com.]

lighting conditions. Therapeutic progress was assessed by estimating the tattoo ink lightening by comparing photographs made at the beginning and at the end of the C6 treatment course. A panel of three dermatologists, who were otherwise not involved in the trial and blinded as to the treatment conditions, independently estimated the level of clearance. Before the actual evaluation a short series of slides from patients not included in this study were shown to provide a gauge for rating improvement. Using this set, consensus was reached among the evaluators regarding the grading system for tattoo ink lightening. If the results differed from each other, the mean value was used for calculation. The level of clearance was graded as follows: grade 1 (0–25%), grade 2 (26–50%), grade 3 (51–75%), grade 4 (76–95%), grade 5 (96–100%). The occurrence of adverse events (hyper-/hypopigmentation, textural changes and scars) before and after the C6 treatment course was also assessed using the same photographs.

Statistical Analysis

All data were analyzed using the Statistical Package for Social Sciences (SPSS/PC+) program (Version 12.0 for Windows), employing non-parametric tests (Mann–Whitney-*U*-Test, Kruskal–Wallis-Test). The significance level was set to $P<0.05$. Descriptive statistics were also calculated (mean, standard deviation, median, minimum, maximum, numbers, percentage rate).

RESULTS

Demographic Details of Patients With Tattoos

The mean age of our patients was 35.8 years. They had received 18.6 (range 12–37) previous treatments with a MedLite$^{\mathrm{TM}}$ C3 1,064-nm Nd:YAG laser and were re-treated five times with a MedLite$^{\mathrm{TM}}$ C6 1,064-nm Nd:YAG laser device for professional tattoo removal. The tattoos were located on the upper arm (33.3%), trunk (33.3%), forearm (22.2%), and lower leg (11.2%) (Table 2).

Beam Profile Analysis

Two- (2D) and three-dimensional (3D) beam profiles were obtained for each spot size (2, 3, 4, 6, 8 mm). The graphics show the general shape of the beam ("flat top" vs. "Gaussian") and the presence of micro-spikes and micro-nadirs of power along a vertical line passing through the center of the beam profile.

C3

The beam shape is "Gaussian" regardless of the spot size. As an example, Figure 1 shows 2D and 3D profiles obtained with the C3 laser using a 450 mJ/cm^2 energy pulse at 4 mm spot size. The spikes of power are numerous enough to reduce the general homogeneity of the beam profile. The center of the beam (red and purple color) represents a 20–30% variation of the light along a vertical line passing through the center of the beam profile (data not shown).

C6

With all spot sizes, the shapes of the beam profiles were rather "flat top" than "Gaussian." Most of the energy applied within this flat top area is equal to the average of the beam energy (Fig. 2).

Mean Energy Density, Mean $E_{\max}$, and Mean Spot Size

The mean energy density applied during all C3 treatment sessions (3.8 ± 0.5 J/cm^2) had been significantly lower compared with the C6 treatment course (4.8 ± 1.3 J/cm^2, $P<0.001$) (Table 2). Additionally, the mean spot size used during the C3 treatments (3.6 ± 0.2 mm) was significantly smaller compared with C6 treatments (5.0 ± 0.9 mm, $P<0.001$).

As reported above (see "Technique"), the mean $E_{\max}$ and the corresponding spot size were significantly larger in C6 treatments as compared with C3 treatments ($P=0.0101$ and $P<0.001$, respectively) (Table 2). During the C3 session with the highest amount of $E_{\max}$, all tattoos were treated with a 3-mm spot size. These 36 tattoos were later

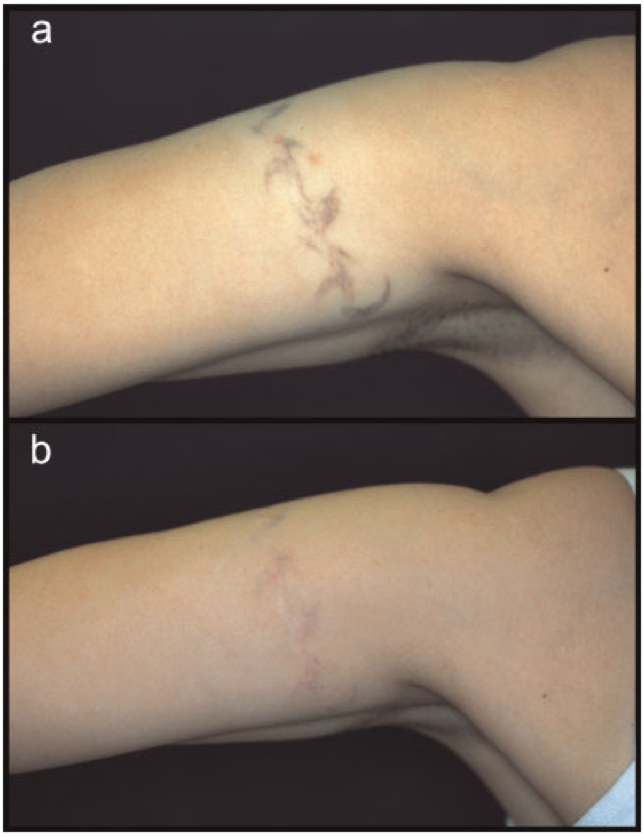

Fig. 3. Female patient with a resistant black tattoo on the right upper arm after 12 C3 treatment sessions (**a**). The finding improved significantly (clearance grade 4) after five additional C6 treatment sessions (**b**). [Figure can be viewed in color online via www.interscience.wiley.com.]

treated with C6 at a spot size of 3 mm ($n = 4$ [11.4%]), 4 mm ($n = 27$ [77.2%]) and 6 mm ($n = 4$ [11.4%]).

Assessment of Clearance

After the C6 treatment course, 33.3% of the tattoos showed a clearance of grade 1 (0–25%), 16.7% of grade 2 (26–50%), 16.7% of grade 3 (51–75%), 30.5% of grade 4 (76–95%), and 2.8% of grade 5 (96–100%) (Fig. 3). The treatment success was not influenced by the localization of the tattoo. Although the tattoos located on the lower arm showed the highest clearance rates and those on the lower leg the lowest clearance rates, the difference was not statistically significant (Table 2; $P = 0.46$).

Side Effects

When patients were included into the trial, 30 (83.3%) of 36 tattoos showed side effects of the previous treatment course (Table 3).

After C6 treatment additional side effects occurred in 3 (8.3%) of 36 tattoos (hyperpigmentation: $n = 2$ [5.6%] and hypopigmentation: $n = 1$ [2.7%]). No additional textural changes and scars were observed.

TABLE 3. Side Effects (Hyper-/Hypopigmentation, Textural Changes and Scars) in 32 Patients (36 Tattoos) After C3 Pre-Treatment and Additional Side Effects After C6 Treatment

	Tattoos	
Side effects	*n*	%
Side effects following C3 pre-treatment (before C6 treatment started)		
No side effects	6	16.7
Hyperpigmentation	3	8.3
Hyperpigm + textural changes[a]	3	8.2
Hyperpigm. + scars	2	5.6
Hypopigmentation	5	13.9
Hypopigm. + textural changes[b]	2	5.6
Hypopigm. + scars	0	0
Textural changes	11	30.6
Scars	4	11.1
Additional side effects following C6 treatment		
No additional side effects	33	91.7
Hyperpigmentation	2	5.6
Hypopigmentation	1	2.7
Textural changes	0	0
Scars	0	0

To calculate the total rate of hyper-/hypopigmentation, textural changes and scars after C3 treatment it is necessary to add up all cases of hyperpigmentation ($3 + 3 + 2 = 8$ cases), hypopigmentation ($5 + 2 = 7$ cases), textural changes ($3 + 2 + 11 = 16$ cases) and scars ($2 + 4 = 6$ cases).

[a] C3-treated patients who developed two different side effects (hyperpigmentation and textural changes/scars).

[b] C3-treated patients who developed two different side effects (hypopigmentation and textural changes/scars).

DISCUSSION

The treatment success with the new generation Q-switched Nd:YAG laser (MedLite$^{\text{TM}}$ C6) was significant (e.g., Figs. 3 and 4). Upon completion of five treatment sessions, we reached clearance rates of 50–100% in 18 out of 36 previously resistant tattoos (Figs. 3,4). The low rate of C6 related side effects (Table 3) in this study is comparable to other reports showing a rate of hyperpigmentation from 2.2% to 44% [5,6] and hypopigmentation from 0% to 7.6% [7,8]. Notably, there were no cases of textural changes and/or scars while others reported this complication in up to 25% [9].

Tan et al. [2] showed that a larger spot size increased the depth of the thermal injury in an experimental setting using a pulsed dye laser. From the present study, we conclude that the improved clearance of previously resistant tattoos is probably attributable to the larger spot size and a larger energy fluence in the deeper layers of the dermis, resulting in less treatment sessions and less

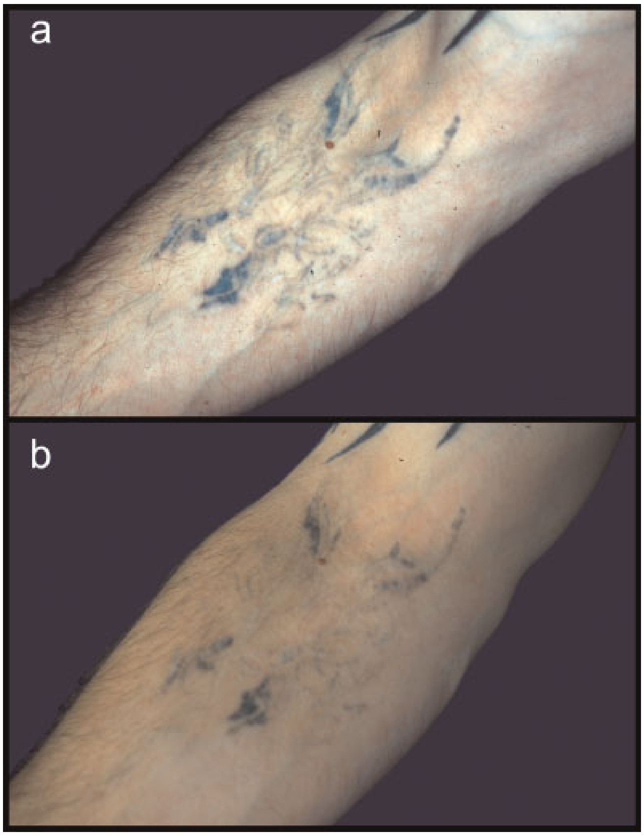

Fig. 4. Male patient with a resistant black tattoo on the right forearm after 12 C3 treatment sessions (**a**). The tattoo was partly removed (clearance grade 3) after five additional C6 treatment sessions (**b**). [Figure can be viewed in color online via www.interscience.wiley.com.]

potential for tissue reaction. The differences in the energy fluences as potential confounding variables should be considered in interpreting the results. Theoretically, the treatment success could be attributed to either "spot size" and/or "energy fluence." Detailed analysis of the energy data (Table 2), however, did not reveal clinically relevant differences during both treatment courses. Mean energy fluence and maximum energy fluence during the C6 treatment course were about 10–20% greater when compared with C3. It is unlikely that this energy difference significantly influenced the clearance rates. One has also to keep in mind, that a change in spot size in some cases has necessitated a change in energy fluence in order to obtain the required clinical endpoint of whitening. In general, small spot sizes require higher fluences because scattering at the edge diffuses the beam and reduces the intensity. Thus, an increase in spot size resulted in only small increments in the laser treatment irradiance during the C6 treatment course.

The interest of a beam profile control has been advocated for different types of lasers [10] but to the best of our knowledge no study has yet addressed this specific parameter for Q-switched Nd:YAG lasers in the setting of resistant tattoos. We carried out a detailed 2D and 3D analysis of the beam profile of both laser systems under standardized conditions using an established laser beam analyzing system (DataRay v.500M4 Software) (Figs. 1 and 2). Although we were not able to demonstrate the actual distribution of light within the skin of the patients, we were able to demonstrate remarkable differences of the beam profile of both laser devices under investigation. While the C3 beam profile shows a power distribution that gets higher towards the center of the beam ("Gaussian," Fig. 1), the C6 profile is more homogenous, and most of the power applied within this area is equal to the average of the beam power ("flat top," Fig. 2). Conceivably, a "flat top" beam improves results by reducing complications due to lower intensity at the surface, whereas the increase of energy density with the C3 laser system was complicated by more bleeding, tissue splatter and pain resulting in a high rate of side effects and prolonged treatment course. Multiple treatments of resistant tattoos often lead to fibrosis and visible textural changes that hamper the response to subsequent treatment.

Limitations of the present study result from the fact that patients had been previously treated with a different laser and from the influence of the number of previous treatments on the tattoo clearance. Thus, a comparison of both methods as first line modalities is impossible, and conclusions with regard to the influence of spot size and energy fluence must be drawn with caution. It is clear, however, that the C6 treatment provides a path out of the dilemma of lack of clearance and side effects that often limits the success of tattoo removal with the C3 laser device. Whether the C6 laser is also more suitable as a first line treatment should be subject of future trials, as should the respective importance of the laser beam's physical properties.

In conclusion, the data provided here draw the attention to the importance of spot size and laser beam profile for the reliability of laser based tattoo removal. The interim response rates are quite encouraging, and the remaining tattoos are expected to achieve further clinical clearance given a sufficient number of further treatments. Since different lasers systems used for tattoo removal display different beam profiles, this parameter should be carefully evaluated when performing head-to-head studies.

Today there is little progress in laser assisted tattoo removal. Theoretical calculations support the argument that picosecond laser pulses should be more effective at clearing tattoo particles than nanosecond pulses. Clinical studies are limited and it is unknown whether resistant tattoos can be treated effectively by high-fluence picosecond pulses [11–13]. Unfortunately, high-energy picosecond pulses are difficult and expensive to generate, so that very small spot sizes (<0.5 mm) would be required to produce high enough fluences. As discussed above, these small spot sizes result in unacceptable scattering losses so that tissue penetration is compromised. In this regard, the authors feel that it might be reasonable to improve already established and clinically proven treatment parameters rather than focusing on the resource-consuming development of novel laser devices.

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