Successful Treatment of Paradoxical Darkening

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Background and Objectives: Tattoo removal can inadvertently lead to paradoxical darkening after laser procedure. We present a new laser device that may treat this unwanted outcome.
Study Design/Patients and Methods: We report two cases from a clinical trial, using a novel picosecond 532 nm and 1,064 nm laser to treat unwanted red tattoos.
Results: Two cases of paradoxical darkening improved with the use of a novel picosecond 532 nm and 1,064 nm laser.
Conclusion: The use of a picosecond 532 nm and 1,064 nm laser may treat paradoxical darkening in red colored tattoos. Lasers Surg. Med. 48:471–473, 2016.
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Key words: picosecond; Nd:YAG; Q-switched; tattoo; laser; paradoxical darkening

INTRODUCTION

Although Q-switched lasers have been established as the gold standard treatment for the removal of unwanted tattoos, the advent of the picosecond 755 nm laser may challenge this paradigm. Regardless, many reports have been described of paradoxical darkening after treating unwanted tattoos using Q-switched ruby (694 nm), Q-switched neodymium (Nd:YAG 1,064 nm/532 nm), and pulsed green dye (510 nm) lasers [1]. Although this unexpected result may occur, it has been reported to resolve with subsequent laser treatments, sometimes necessitating surgical excision [1]. When patients observe this phenomenon, the trust in their provider may be questioned.

Very few studies have been conducted to explain the occurrence of paradoxical darkening. Ross et al. [2] concluded that titanium was found to be overrepresented in biopsy specimens analyzed in darkened tattoos after laser treatment. Titanium dioxide (TiO_2) is used to enhance the brilliance of tattoos [3] and can be found in green, white, and flesh colored tattoos, but can be seen in many other colors [4]. Mercury was also reported to be seen in a red colored tattoo that darkened after treatment with frequency-doubled Nd:YAG laser with fluences of 2–4 J/cm^2 and spot size of 2–3 mm [2].

We describe a small case series of paradoxical darkening observed using a Q-switched frequency-doubled Nd:YAG and a novel picosecond Nd:YAG laser with successful resolution.

CASE 1

A 23-year-old Caucasian man presented with an unwanted black and red colored tattoo on the right upper arm. One half of the red colored tattoo was treated with a Q-switched frequency-doubled Nd:YAG (Lutronic, Freemont, CA) using a 3.4 mm spot size with 3 J/cm2 fluence and the other half was treated with a novel picosecond frequency-doubled Nd:YAG laser (Cynosure, Westford, MA) using spot sizes ranging from 2.5 nm to 4 mm and fluences ranging from 0.3 J/cm^2 to 1.2 J/cm^2. At follow-up visit, 1 month later, the side treated with the Q-switched frequency-doubled Nd:YAG had black discoloration, whereas the novel picosecond frequency-doubled Nd:YAG laser-treated area did not have any signs of paradoxical darkening. The black discoloration along with the red colored tattoo was treated with the picosecond frequency-doubled Nd:YAG laser using spot sizes ranging from 2.7 nm to 4.5 mm and fluences ranging from 0.4 J/cm^2 to 1.4 J/cm^2. At subsequent follow-up visit, the black discoloration significantly improved along with the red tattoo ink (Fig. 1).

CASE 2

A 27-year-old Caucasian woman requested removal of an unwanted black and red colored tattoo on the right buttock. One half of the red colored tattoo was treated with a Q-switched frequency-doubled Nd:YAG (Lutronic) using a 3.4 mm spot size with 3 J/cm^2 fluence and the other half was treated with a novel picosecond frequency-doubled Nd:YAG laser (Cynosure) using spot size and fluence of 2.5 mm and 1.2 J/cm^2, respectively.

At follow-up, visit 1 month later, both treated areas demonstrated paradoxical darkening. The black discoloration on the upper and lower portion of the tattoo was subsequently treated with the picosecond 532 nm and 1,064 nm Nd:YAG laser (Cynosure), respectively (the tattoo was divided, therefore only one laser was used on each area of the tattoo). The following parameters were

Conflict of Interest Disclosures: All authors have completed and submitted the ICMJE Form for Disclosure of Potential Conflicts of Interest and none were reported.

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Accepted 18 January 2016
Published online 2 February 2016 in Wiley Online Library (wileyonlinelibrary.com).
DOI 10.1002/lsm.22482

Fig. 1. From left to right: before treatment; paradoxical darkening on one half of tattoo; resolution of paradoxical darkening.

utilized: 532 nm: 3.7 mm spot size, 0.9 J/cm^2 fluence and 1,064 nm: 3.5–4mm, 1.4–1.7 J/cm^2. The patient was treated again 1 month later with similar parameters (slightly lower fluence of 1.2–1.6 J/cm^2 using the 1,064 nm picosecond laser). At follow-up visit, the black discoloration significantly improved along with the red tattoo ink (Fig. 2).

To minimize pain, the patients were administered subcutaneous lidocaine 1% with epinephrine 1:100,000 prior to treatment.

DISCUSSION

Paradoxical darkening after laser treatment was originally described by Anderson et al. [1] in 1993 using a Q switched and pulsed dye laser for cosmetic tattoos. Since their report, several additional cases have been described [2,5–11]. This phenomenon has been theorized to be caused by reduction of ferric oxide, which is a rust color (used commonly in red, pink, and flesh colored tattoos), to ferrous oxide, which is jet black [1]. Comparably, tattoos with titanium dioxide have been shown to turn a blue color as a result of reduction of Ti^{4+} to Ti^{3+} [12]. In an investigation by Tope et al. [13], tattoo ink darkening was not observed when using pulse durations greater than 1 ms. The authors suggest that a threshold power density is required to cause tattoo ink darkening in tattoos containing titanium. No other theories or explanations other than those mentioned have been shared to explain this phenomenon. In our case, the theory postulated by Tope et al. does not apply.

Tope's power threshold argument applies both to Q-switched and picosecond lasers on ferric oxide. The 532 nm Q-switched laser power density that caused darkening was 0.6 $J/(cm^2 \times ns)$ for 5 ns pulses and 3.4 mm spot, and the 532 nm picosecond laser power density was 1.6 $J/cm^2 \times ns)$ for 0.75 ns pulses and 2.5 mm spot. Based on Monte Carlo models and the physics of light tissue interaction, energy to a deep target is approximately up to 80% higher for the same fluence through a 3.4 mm versus 2.5 mm spot size. So, the "equivalent" power density for the Q-switched laser treatment at the target is proportional to 1.1 $J/(cm^2 \times ns)$ versus 1.6 $J/(cm^2 \times ns)$ for picosecond laser treatments. The picosecond laser both did (case 2) and did not (case 1) cause darkening on red ink at the same power density, whereas the Q-switched laser caused darkening in both cases. Although the picosecond laser is at a higher power density, the energy at the target ($\sim$1.2 J/cm^2) with picosecond laser is about 4.5 times less than the energy at the target with the Q-switched laser ($\sim 3.0 \times 1.8 = 5.4$ J/cm^2) because of the shorter pulse width. Since the pigment heating (peak temperature) scales with energy, the Q-switched laser heats more than the picosecond laser. This argues in favor of a energy threshold rather than a power density threshold as originally described by Tope et al. Apparently, the target energy of the Q-switched laser is well above threshold, whereas the picosecond laser treatment is close to threshold where small differences in

Fig. 2. From left to right: before treatment; paradoxical darkening on entire tattoo; resolution of paradoxical darkening.

skin pigment or scatter could give rise to the two different results seen in cases 1 and 2.

The 532 nm and 1,064 nm picosecond laser may be advantageous over the Q-switched Nd:YAG laser for the treatment of paradoxical darkening as overall less energy is needed. Picosecond laser causes less heating, so that further darkening may be avoided and other heat-related side effects can be minimized. Furthermore, the greater mechanical disruption of pigment particles with picosecond pulses (breaking up particles into smaller parts that are more easily phagocytosed) may be an additional benefit of the picosecond laser. Although we did not compare the use of the 532 nm and 1,064 nm picosecond laser to the Q-switched Nd:YAG laser once we observed paradoxical darkening, we hypothesize that the use of the Q-switched laser on the darkened area may reduce the darkened pigment also, but may likely have required more treatments.

Finally, larger spot sizes and lower fluence may increase ink removal efficacy while decreasing the chance of hypo/hyperpigmentation in darker skin types.

Our case series was an observation, not a clinical trial. Therefore, prospective, blinded, controlled clinical trials are needed to further study the treatment of paradoxical darkening using the 532 nm and 1,064 nm picosecond laser.

At present time, no investigations comparing side-to-side treatment demonstrating paradoxical darkening with lasers of the same wavelength have been published. Furthermore, there are no published articles on improving paradoxical darkening with a picosecond laser. The new picosecond Nd:YAG has the potential to become the gold standard when addressing paradoxical darkening after laser tattoo treatment.

ACKNOWLEDGMENTS

We would like to thank the Research Department at the Laser and Skin Surgery Center of New York and James Childs, PhD, for their support.

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