Fractional Er:YAG Skin Conditioning for Enhanced Efficacy of Nd:YAG Q-Switched Laser Tattoo Removal

Leonardo Marini[1] , Jasmina Kozarev[2] , Ladislav Grad[3], Matija Jezeršek[3], Boris Cencič[4]
[1]The Skin Doctors' Center, Trieste, Italy
[2]Dr. Kozarev Dermatology Laser Clinic, Sremska Mitrovica, Serbia
[3]University of Ljubljana, Ljubljana, Slovenia
[4]Fotona d.d., Ljubljana Slovenia

ABSTRACT

In this study a new approach to laser tattoo removal is proposed. Although Q-switched laser systems have become the gold standard in tattoo removal, they also have their limitations. To overcome existing procedure limits, pre-treatment conditioning of the skin with a fractional Er:YAG laser was studied. Laser-drilled micro channels known as skin perforations were found to enhance the efficacy of the laser tattoo-removal process, while reducing the healing time and enabling effective multiple treatments during each session.

Key words: Q-switched laser, tattoo removal, Er:YAG laser fractional treatment, photoacoustic effect

Article: J. LAHA, Vol. 2012, No.1; pp. 35-40.
Received: March 15, 2012; Accepted: April 26, 2012.

I. INTRODUCTION

Laser tattoo removal has been proven as an effective and patient friendly procedure with virtually no side effects [1,4,8,9,13,18,21]. Most tattoo procedures take only a few minutes, but several treatments are typically necessary to completely remove a tattoo.

The treatment is based on a process of pigment disintegration caused by strong acoustic waves generated during the interaction between extremely short Q-switched laser pulses (of a few nanoseconds duration) and the tattoo pigment particles. The colored tattoo particles are then more easily removed by the body's own immune system. Three-week-long intervals between sessions are required to allow the pigment residue to be cleared by the body [16].

The initial pigment breakup is only one stage in its successful removal. Several mechanisms are assumed possible. The smaller fragments may be phagocytosed and subsequently eliminated by the lymphatic system. [17]. Another possible removal process is pigment chemical decomposition into gaseous products [6]. Direct ablation of the pigment can also take place, with skin damage as a negative side effect. Physical alteration and redistribution of the pigment may also account for its reduced visibility [5].

Since it is highly desirable for patients and practitioners to maximize the efficacy of each treatment and to reduce the number of needed treatments, there has been extensive research conducted into the physical mechanisms of the laser-tattoo-tissue interaction process.

The efficacy of each treatment depends on the energy of the disruptive acoustic wave produced during the interaction between the laser and tattoo color. Laser light energy is absorbed in the tattoo pigment by means of selective photothermolysis, and the majority of the Q-switched laser pulse is then converted into acoustic energy.

The laser wavelength has to be adjusted to match the tattoo color so that the absorption of the laser light into the tattoo pigment can be maximized. Nowadays, the most popular tattoo removal laser is Nd:YAG (1064 nm), which is perfectly absorbed in the most common tattoo colors, black and dark blue. With the addition of a KTP crystal and different dyes, the Nd:YAG laser wavelength can be converted into other wavelengths, like 532 nm, 585 nm and 650 nm. These wavelengths are effectively absorbed in the following colors: red, purple, orange, sky blue and green.

Aside from the laser's wavelength, the duration and energy of the laser pulse are the most important parameters. They define the peak pressure of the laser-induced acoustic waves in the tattoo pigment. To protect the surrounding tissue from the heat and to achieve effective conversion of the absorbed laser light into the acoustic wave, extremely short laser pulses are required. Taking into account today's commercial laser technology, Q-switched lasers in the nanosecond range are the most effective in generating acoustic waves.

Any shielding of the tattoo color by plasma formation in the air or extensive scattering in the skin might dramatically reduce the absorption in the pigment and its overall conversion into the acoustic energy. Immediately after every Q-switched treatment, a pronounced whitening occurs as a result of pressure-induced micro damage and increased dermal intercellular fluid flow. It is a typical skin response with a shielding effect that results in negligible efficacy for additional consecutive pulses [7, 20, 22].

On the other hand, with larger energies of acoustic waves, side effects start to appear more frequently. According to today's understandings, cavitation bubbles, which are formed around the pigment particles due to their increased temperature and plasma formation, can damage the surrounding tissue, as proved with histologic and electron microscopic analyses of biopsies [4, 5]. Measurements of acoustic waves [22] clearly show the existence of a laser fluence threshold at which uncontrolled skin perforation as a side effect occurs. It represents the limit for applied laser pulse parameters. Occasional side effects such as dyspigmentation, allergic reactions, ink darkening, and epidermal debris are reported as well [10, 11, 13].

To improve laser tattoo removal efficacy and safety, fractional resurfacing was proposed to complement and increase the efficiency of the Q-switched laser treatment [12,14,19, 23]. The proposed method is based on the partial removal of tattoo pigment by ablation; in such cases a lower volume of the pigment needs to be cleared by the lymphatic system and the probability for allergic skin reactions is decreased. As opposed to treatment combinations where fractional resurfacing is performed after Q-switched laser tattoo removal, we believe that fractional skin resurfacing performed before Q-switched laser tattoo removal (see Fig.1) will have a greater impact on the efficacy and safety of the laser tattoo removal treatment .

Fig 1: Micro holes in the skin produced with fractional Er:YAG .

In this paper, an improvement of the laser tattoo removal protocol is described based on a combination of ablative fractional Er:YAG skin resurfacing and Nd:YAG Q-switched laser treatment. Preliminary clinical experience with the newly developed protocol has proved the benefits of this combined technique.

II. MATERIALS AND METHOD

a) Determination of skin damage threshold

Determination of the skin damage threshold and its shift to larger fluences after fractional Er:YAG laser skin conditioning was performed by optodynamic monitoring of the process. A LBDP (laser beam deflecting probe) was used as shown in Fig. 2 [22]. We used a Q-switched Nd:YAG laser (Fotona model QX MAX) delivering 6 ns FWHM pulses with a top hat profile and wavelength of 1064 nm. The laser beam diameter was 4 mm in all experiments. The laser tattoo removal process was monitored using two techniques: The optodynamic waves in the surrounding air were measured by the laser-beam deflection probe (LBDP). The treated spot is optically observed with microscope type Leica M205C and magnification 10x.

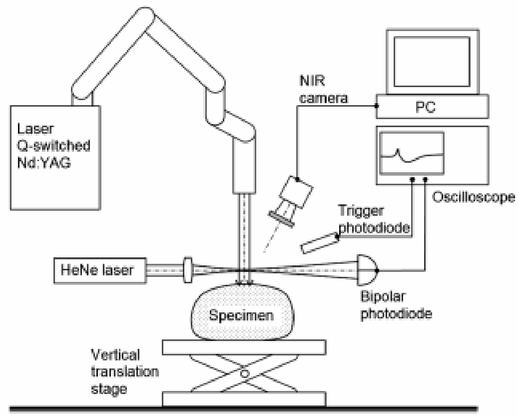

Fig. 2: Experimental set up.

The experiments were performed ex vivo and in vivo. Tattooed marks on pig skin were used for the ex vivo measurements. In such experiments, pig skin is assumed to be a good replacement for human skin [22]. The advantage of using these samples was their availability and the possibility to use laser parameters beyond their safe range. The measurements in vivo were performed on the tattooed skin on the right forearm of one patient with no previous removal attempts. The tattoo was black and amateur in origin.

Typical LBDP signals are shown in Fig. 3. Damage to the skin might be precisely detected by analyzing the shape of the signal as shown in the figure.

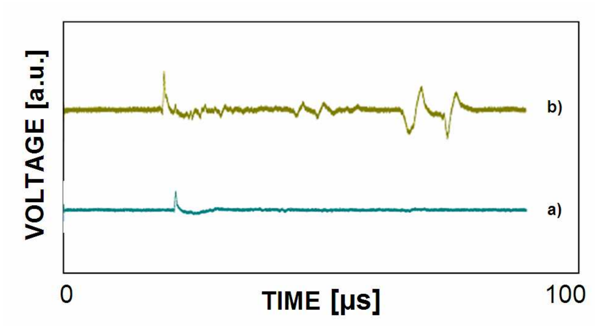

Fig.3: The LBDP response of tattooed skin to Q-switched laser pulses with different fluences. a) below damage threshold b) above damage threshold.

Measured damage threshold of the skin above the tattoo was 4 J/cm². Applying fractional Er:YAG skin conditioning before the treatment with Q-switched Nd:YAG laser increases the skin damage threshold to 8 J/cm². From Fig. 4 one can clearly see that fractional Er:YAG skin conditioning enables the practitioner to use higher fluences without damaging the skin.

Fig 4: Picture of treated spots with the fluence 5 J/cm².
a) unconditioned skin;
b) skin pre-conditioned with fractional Er:YAG laser.

b) New two-step procedure in laser tattoo removal

A new approach in laser tattoo removal consists of two steps. In the first step, the skin is conditioned in a way to protect damages at higher fluences. By drilling micro holes in the skin to a depth close to the tattoo pigment, the subsequent Q-switched laser-induced internal pressure and gases can be released through micro channels without breaking skin structure.

Typical parameters used in a first step were Er:YAG laser, MSP pulses, Turbo 3 and 18 J/cm².

Fig. 5: Step 1: Fractional Er:YAG skin conditioning with Fotona Er:YAG laser scanner model F22.

Fig. 6: Immediately after 1st step.

The second step is classical Q-switched laser tattoo removal with the possibility to use higher fluences and to begin the second treatment at the same session with only a 20-minute delay from the first treatment.

Fig.7: Step 2: Nd:YAG Q-switch laser treatment of the tattoo with Fotona QX MAX

Fig.8: Immediately after 2nd step.

c) Clinical evaluation of the new procedure in laser tattoo removal

Clinical evaluation studies of the new proposed tattoo removal procedure were performed in two clinics. In both clinics, more than twenty patients with tattoos were treated.

In the first clinic (Dr. Kozarev Dermatology Laser Clinic), fractional Er:YAG laser skin conditioning (typical 10% coverage) was applied to a half of the tattoo, and afterwards a Q-switched Nd:YAG laser was used to treat the entire tattoo (typical spot size 4–6 mm and fluence 3.8–7 J/cm^2). Patients received three to seven treatments during the period of May 2011 to February 2012. Standard photographs were taken before each treatment. The treatment sites were evaluated compared with the initial (pre-treatment) condition regarding the skin texture, pigments, blister formation, scaring and pain level during the procedure according to VAS.

In the second clinic (The Skin Doctors' Center), higher fluences and multiple treatments at one session were applied to demonstrate how much faster the tattoo removal process can be.

III. RESULTS

The proposed new two-step procedure in laser tattoo removal has been found to be a faster, more effective and more patient friendly treatment, with a reduced probability for side effects. The results can be concluded as follows:

a) No whitish blister

In all patients, skin conditioning with ablative fractionated Er:YAG laser allow the increased dermal intercellular fluid to be released very fast, rather than to build up and form a sub-epidermal whitish blister.

b) Reduced pain level

In the zone of fractional laser treatment, the pain level in the VAS scale was significant lower (α=001).

c) Faster healing time

In the area of Q-switched-only laser treatment, the release of fluid, the edema and subsequent subepidermal blistering was higher, resulting in a 3-day longer healing time compared to the zone treated with fractional laser and Q-switched laser. Even by employing higher fluencies, there were no pigment dischromia.

d) Increased tattoo clearance

This combined technique for laser tattoo removal appears to increase tattoo clearance. Probably some amount of the pigment is released out of the skin by the ablative process or through the ablated micro channels.

e) Reduced number of treatment sessions

By enabling two effective treatments at one session and the use of higher fluencies, the number of sessions can be substantially reduced. Typically a 30% reduction of sessions can be achieved. At the moment, adding more than two treatments per each session does not provide any additional benefits.

Case: Multicolored tattoo removal in 3 sessions
Used parameters:
Step 1: Er:YAG, F22, MSP, turbo 3, 18 J/cm^2
Step 2: Q-sw. Nd:YAG, 4 mm, 5.0-7.5 J/cm^2, 10 Hz and Q-sw. 532 nm, 3 mm, 1.8 J/cm^2, 6 Hz

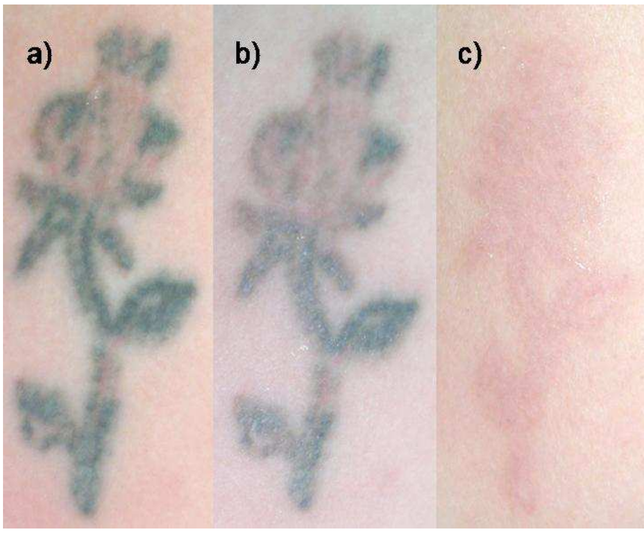

Fig. 9: Multicolored tattoo case: a) Before treatment, b) 2 months after 1st treatment c) after 3rd treatment (4 months after first treatment). Courtesy of dr. Kozarev.

IV. DISCUSSION

Though Q-switched laser systems have become a gold standard in tattoo removal, they have their limitations. The main concern is that it is a multi-session treatment and that the removal of a complex professional tattoo might take more than a year. So it is imperative for patients and practitioners to maximize the efficacy of each treatment and to reduce the number of needed treatments. A straightforward approach is by enlarging single-pulse energy. However, modern laser technology with single-pulse energies over 1.5 J have reached a limit where other approaches are needed to further increase tattoo-removal efficacy without causing skin damage or other side effects.

Strong acoustic transients generated during the laser-tissue interaction damage the skin. Enabling the release of the mechanical wave energy without causing any damage to the skin was a great challenge. The introduction of micro gas- and pressure-release channels in the skin, as proposed in this paper, dramatically increase the skin damage threshold. These act as pressure relief ducts through which the gasses, which result from the thermal decomposition of the pigment, can escape without building up excessive pressure. The stress is reduced for the same fluence or the fluence can be increased for the same stress and damage level. Based on the study of the optodynamic effect and preliminary clinical research on more than twenty patients, we can conclude that the proposed new procedure has the following advantages:

a) Increased damage threshold of the skin

By preparing channels to allow pressure release, the damage threshold of the skin is enlarged, which means higher fluences can be safely applied. Taking into account that higher fluences are more effective in tattoo removal, it means that with a single treatment a higher volume of tattoo pigment can be disintegrated and removed.

b) Increased efficacy of tattoo pigment disintegration by inducing multi-center plasma formation

By changing the surface of the skin with a network of ablated channels, the optical properties of the laser beam path have changed as well. Theoretically, multi-center plasma formation can occur, which may lead to enhanced mechanical pressure spots in the tattoo pigment. Nevertheless, this effect is pronounced only when fluencies are used just above the plasma formation threshold.

c) Enable effective use of multiple treatments in one session

Observed increased release of dermal intercellular fluid without forming substantial sub-epidermal whitish blisters allows multiple treatments in one session. However, our preliminary results show that adding a third treatment in the same session does not yield an observable difference in tattoo clearance.

d) Removal of tattoo pigment by ablation

Q-switched laser tattoo removal is based on three mechanisms: transepidermal elimination, removal via lymphatics and rephagocytosis by other cells in the dermis. By ablative elimination and elimination of the tattoo pigment through a perforated epidermis, the load on the lymphatic system is reduced and consequently also the possibility of allergic reactions [9,10].

e) Removal of tattoo pigment by healing of perforated skin.

It is known that the wound-healing process is much faster in the case of a fractionated wound. It is assumed [19] that in the case of a fractionated wound, additional tattoo ink might be removed during the healing process.

V. CONCLUSIONS

A new approach to laser tattoo removal has been presented, which for the first time utilizes a combination of ablative fractional treatment of the skin together with Q-switched Nd:YAG laser tattoo removal. An ablative fractional treatment used prior to the treatment with the Q-switched laser enables the use of higher single pulse energies, multiple treatments in a single session, and finally, a reduced number of needed treatment sessions, while simultaneously avoiding various known side effects.

Acknowledgment

This research was carried out in a collaboration with the EU regional Competency Center for Biomedical Engineering (www. bmecenter.com), coordinated by Laser and Health Academy (www. laserandhealthacademy.com), and partially supported by the European Regional Development Fund and Slovenian government. One of the authors (L. Marini) thanks Fotona d.d. for the loan of laser equipment.

VI. REFERENCES

1. Goldman L. et al., "Radiation from a Q-switched ruby laser. Effect of repeated impacts of power output of 10 megawatts on a tattoo of man," J. Invest. Dermatol. 44,69–71 (1965).
2. Anderson R. R. and. Parrish J. A, "Selective photothermolysis—precise microsurgery by selective absorption of pulsed radiation," Science 220(4596), 524–527 (1983).
3. Polla L, Margolis R, Doverwhitaker D, Murphy GF, Jacques S, Anderson R: Melanosomes are the primary target target of Q-switched ruby laser irradiation in guinea pig skin. J Invest Dermatol 89: 281–286 (1987).
4. Ferguson J. E. et al., "The Q-switched neodymium:YAG laser and tattoos: a microscopic analysis of laser-tattoo interactions," Br. J. Derma- tol. 137(3), 405–410 (1997).
5. Ross E. V. et al., "Comparison of responses of tattoos to picosecond and nanosecond Q-switched neodymium: YAG lasers," Arch. Dermatol. 134, 167–171 (1998).
6. Ho D. D. et al., "Laser-tattoo removal—a study of the mechanism and the optimal treatment strategy via computer simulations," Laser. Surg. Med. 30(5), 389–397 (2002).
7. Nahen K. and Vogel A., "Plume dynamics and shielding by the ablation plume during Er:YAG laser ablation," J. Biomed.Opt. 7(2), 165–178 (2002).
8. Adatto M. A., "Laser tattoo removal: benefits and caveats," Med. Laser Appl. 19(4), 175–185 (2004).
9. Bernstein E. F., "Laser treatment of tattoos," Clin. Dermatol. 24(1), 43–55 (2006).
10. Anton H, Susan B, Vicki L. Adverse Effects of Q-Switched Laser Treatment of Tattoos. *Dermatologic Surgery*.118-122., (2008).
11. Kaur RR, Kirby W, Maibach H. Cutaneous allergic reactions to tattoo ink. *Journal of Cosmetic Dermatology*.;8:295-300, (2009).
12. Eronemus R.. Combining Fractional Resurfacing and Q-Switched Ruby Laser for Tattoo Removal. *Dermatologic Surgery*.:1-3. (2010).
13. Choudhary S. et al., "Lasers for tattoo removal: a review," Laser. Med. Sci. 25(5), 619–627 (2010).
14. Weiss E.T., Geronemus R.G., Combining fractional resurfacing and Q-switched ruby laser for tattoo removal, Dermatologic Surgery, 36:1-3, (2010).
15. Cencič B. et al., "High fluence, high beam quality Q-switched Nd: YAG laser with optoflex delivery system for treating benign pigmented lesions and tattoos," J. Laser Health Academy, 2010(1), 9–18 (2010).
16. Adatto MA, Halachmi S, Lapidoth M. Tattoo Removal. Current Problems in Dermatology.;42:97-110 (2011).
17. Irkoren S. et al., "The Q-switched Nd:YAG laser in tattoo removal and the effect of lymphatic elimination: an experimental study in rabbits," Surg. Sci. 2(5), 262–268 (2011).
18. Kossida T, Rigopoulos D, Katsambas A. Optimal tattoo removal in a single laser session based on the method of repeated exposures. *Journal of American Dermatology*.;66(2):271-277 (2011).
19. Ibrahimi OA, Syed Z, Sakamoto FH, Jd MMA, Anderson RR. Treatment of tattoo allergy with ablative fractional resurfacing: novel paradigm for tattoo removal. *Journal of American Dermatology*. 64(6):1111-1114 (2011).
20. Jezeršek M, Grad L, Požar T, et al. Optodynamic monitoring of laser tattoo removal. In: Sroka R, ed. *Medical Laser Applications and Laser Tissue Interactions V*.Vol 8092. SPIE-OSA Biomedical Optics;:Vol.809214 1-8 (2011).
21. Kent KM, Graber EM, Laser Tattoo Removal: A Review, Dermatol Surg. Jan;38(1):1-13 (2012).
22. Cencic, B., Grad, L., Možina, J., & Jezeršek, M. Optodynamic monitoring of laser tattoo removal Optodynamic monitoring of laser tattoo removal. *Journal of Biomedical Optics*, *17*(4), 0470031 - 0470036. doi: 10.1117/1.JBO.17.4.047003 (2012).
23. Stankiewicz K. et all, Searching for optimal tattoo removal: a side by side comparison., presetned at ASLMS conference, Kissimmee, USA, April 18-20, (2012).