FRAC3: Three Dimensional Non-Ablative Fractional Laser Skin Rejuvenation

Matjaz Lukac,[1] J. Zabkar, M. Gorjan, Tom Sult M.D. [2]

[1]Institut Josef Stefan, Light and Matter Dept., Ljubljana
[2]Laser Aesthetics, Wilmar, MN 56201, USA

ABSTRACT:

A novel self-induced non-ablative three-dimensional fractional *FRAC3®* method for skin rejuvenation is described. The method utilizes short pulse duration/high peak power density of Nd:YAG *Accelera* mode laser pulses. The *Accelera* pulses produce a three-dimensional fractional pattern in the epidermis and dermis, with damage islands located predominantly at the sites of skin imperfections. Thermal measurements in-vivo of skin surface and in-vitro of skin cross section following the illumination with Nd:YAG *Accelera* pulses are presented. The measurements demonstrate the emergence of isolated »fractional« hot islands within the skin. Clinical experience following the short pulse Nd:YAG laser treatment is also presented. The *FRAC3®* technique offers practitioners another dimension in safety and self-regulating efficacy of non-ablative laser skin rejuvenation.

Key words: laser skin rejuvenation, fractional, Frac3, VSP technology, Nd:YAG lasers, scanner

INTRODUCTION

Fractional laser skin rejuvenation has recently gained a lot of interest due to the fact that the remaining healthy tissue around the fractional damage spots can act as healing centers [2]. A disadvantage of the current approach is that the fractional illumination is only in a form of a two dimensional matrix, and the illuminated columns below the spots are damaged uniformly (see Fig.1 b). In addition, the technique is non-selective with regard to local skin imperfections. Finally, the technique requires a special fractional delivery device. Here, we describe a novel skin self-induced *FRAC3®* laser method, [1,15] based on Fotona Nd:YAG short pulse mode (Accelera) characteristics [9]. The method produces a three-dimensional fractional pattern within the epidermis and dermis, with damage islands located predominantly at the sites of minute skin imperfections and/or inhomogeneities (See Fig.1c).

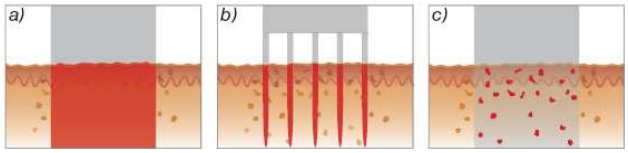

Fig.1. Laser induced damage islands as healing centers: a) standard uniform laser treatment; b) standard two-dimensional fractional treatment; and c) novel self-induced three-dimensional FRAC3 laser treatment.

If the clinical objective is to cause selective modifications of a specific tissue structure, the laser wavelength should match the highest absorption of the targeted structure relative to surrounding tissue. Typically, however, the wavelengths that are highly absorbed in skin imperfections are also highly absorbed by, for example, melanosomes, [4] or hemoglobin containing RBC [3]. These wavelengths do not reach deeper lying skin imperfections, and can result in excessive damage to the healthy skin structures. For this reason, it is often better to select a laser wavelength that penetrates more deeply into the tissue, and achieve selective tissue modification by adjusting the laser pulse duration to the thermal relaxation time of the targeted imperfection. Namely, during a lengthy laser exposure, most of deposited heat may diffuse away from the target structure, resulting in nonspecific thermal damage to adjacent structures. Conversely, a suitably short laser pulse confines the heating effect to the target structure, resulting in maximum temperature difference between the target and adjacent structures [5]. Using a homogeneously penetrating Nd:YAG (λ=1064 nm) laser wavelength, [6-8] and targeting skin imperfections by adjusting the laser pulse duration to the cooling times of these imperfections is the paradigm behind the latest *FRAC3®* minimally invasive skin rejuvenation technique.

PULSE DURATION CONSIDERATIONS

Upon irradiation with a suitable short laser pulse, energy is deposited in the absorbing structure before much heat can be transferred to the surrounding tissue by conduction. The resulting temperature rise in an optically and thermally homogenous structure is thus

directly proportional to the absorbed heat, which is in turn proportional to the laser fluence (in J/cm^2) in the target. In general, however, a significant fraction of the deposited heat may diffuse away from the absorbing structure during laser exposure, which reduces the peak target temperature and impairs the heating spatial selectivity even if the wavelength provides selective absorption of laser energy. Therefore, selection of laser pulse duration, which governs spatial confinement of deposited heat in absorbing structures, is very important. Only laser pulses t_p that are significantly shorter than the target thermal relaxation time τ enable a maximal temperature rise in the targeted structure. Here, the relaxation time τ represents the time interval in which the amplitude of a hypothetical temperature rise decreases by approximately a factor of 2 due to the diffusion of heat into surrounding tissue.

Approximately, the thermal relaxation time depends on the skin structure diameter (d), and thermal diffusivity of skin (α = 0.11 mm^2/s) as

$$\tau = d^2/20\,\alpha \quad . \qquad (1)$$

Note that the exact formula depends on the shape of the skin structure [7].

In what follows we shall somewhat arbitrarily set that the selective heating of a skin structure occurs when laser pulse duration is by a factor of two smaller than the relaxation time τ of the skin structure. Figure 2 shows the dependence of the minimal size d of the imperfection that can be selectively heated by a laser pulse of duration t_p. According to Fig.2, confinement of laser energy within smaller structures requires progressively shorter pulse durations. For structures smaller than 100 μm, pulse durations below 1 ms must be used.

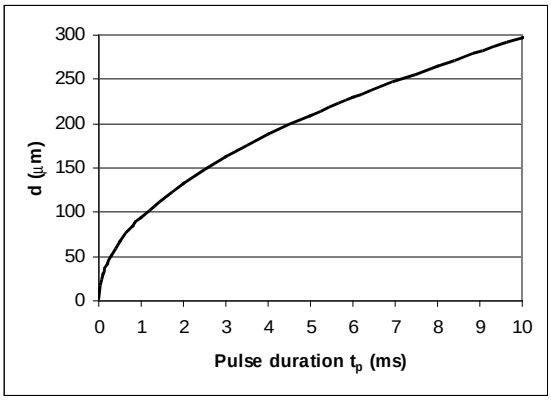

Fig.2.: Minimal size (d) of a skin structure that can be selectively heated by a laser pulse of duration t_p.

Inasmuch as pulses significantly shorter than τ provide the highest temperatures, is the best approach to use extremely short pulses (tp << 50 μs) to ensure heat confinement in skin structures of all sizes? The answer is no. First, explosive vaporization of selectively absorbing hemoglobin can occur when pulses shorter than 10 μs are used [3]. Similarly, epidermal melanosomes can be non-uniformly overheated for laser pulses below 25 μs [4]. The safest and most effective pulse durations for minimally invasive skin rejuvenation are therefore in the 100-400 μs range.

FRAC3: THREE DIMENSIONAL FRACTIONAL SKIN REJUVENATION

When Nd:YAG laser pulses in the 0.1-0.4 ms range are used a selective heating of small skin imperfections and inhomogeneities occurs throughout the illuminated skin tissue. Fractional islands of thermally affected skin structures that are formed in the three dimensional skin tissues are the basis for the latest *FRAC3®* approach to minimally invasive skin rejuvenation.

Thermal skin measurements have been performed in order to confirm the *FRAC3® self-induced* three-dimensional distribution of heat within the skin [1]. A Fotona XP Nd:YAG laser system operating in the *FRAC3®* Accelera (t_p=0.1-1ms) and standard Versa modes (tp=2-200 ms) and a thermal imager, model Sagem Matis, operating in the 3-5 μm spectral range were used. The experimental set-up is shown in Fig. 3.

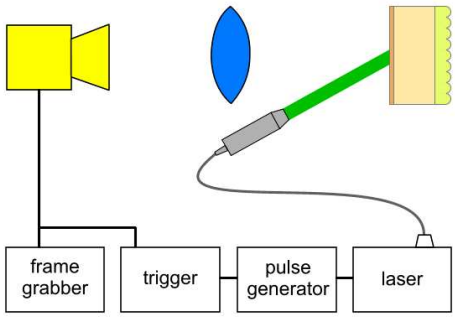

Fig.3: Experimental set-up for thermal imaging measurements.

Skin surface measurements of the temperature distribution following an Nd:YAG laser pulse with a 4 mm spot size were performed in-vivo on patients' hands. Figure 4a shows a typical skin temperature profile following a standard 20 msec long Versa Nd:YAG pulse, and Fig.4 b shows the temperature profile following a short duration 0.3 msec Accelera pulse.

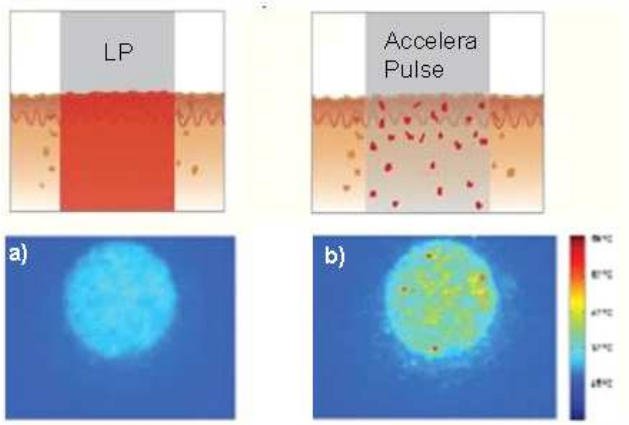

Fig. 4: Skin surface temperature thermal image following a 20ms (a), and a 0.3 ms (b) Nd:YAG laser pulse.

Self-induced temperature fractionality can be observed only following the illumination with the short Accelera pulses. At standard long pulse durations heat conduction from the skin inhomogeneities to the surrounding tissue prevents temperature build-up, and no hot skin islands are observed. This is shown in Fig. 5 where a patient's dorsal hand skin, when illuminated by a Nd:YAG laser of 4 mm spot size, 50J/cm^2 and delivery of different pulse durations, ΔT temperature profiles are observed. Only the 0.2 ms laser pulse results in a significant self-induced temperature fractionality.

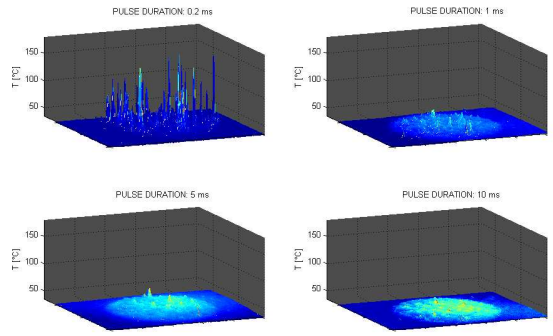

Fig. 5: Skin surface temperature profiles (ΔT) following a 50J/cm^2 Nd:YAG laser pulse of different pulse duration.

The dependence of the *FRAC3*® effect on the pulse duration for a Fitzpatrick skin type I-II can be seen in Fig. 6 that shows the dependence of the fractional temperature increase ΔT on the laser pulse duration. The shown fractional temperature increase represents an average value of the highest ten temperature peaks at each laser pulse duration.

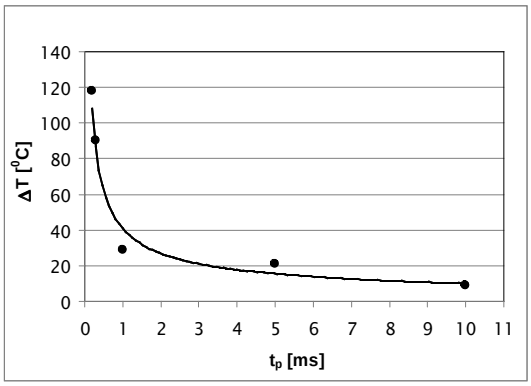

Fig. 6: Measured fractional temperature increase ΔT at the skin surface (Fitzpatrick type I-II) as a function of the Nd:YAG laser pulse duration (32J/cm^2, 3 mm spot size).

Since the size of the observed skin imperfections close to the skin surface are on the order of 50 μm, the fractional temperature increase becomes appreciable below pulse duration of 0.5 ms, in agreement with the previous discussion and Fig. 2. Note that the *FRAC3*® enhancement of the temperature increase is by a factor of twelve when the laser pulse duration is reduced from 10ms to 0.2ms.

Assuming the size and absorption characteristics of the deeper lying fractional targets to be of the same order as observed at the skin surface, we can calculate fractional temperature increase for these targets (such as microvasculature) from experimental data shown in Fig.6, and by taking into account a reduction of the laser fluence with skin depth due to the laser light absorption and scattering. Figures 7 and 8 show the calculated fractional temperature increase (ΔT) at different skin depths as a function of the laser pulse duration, correspondingly for two laser fluences, 40 and 20 J/cm^2.

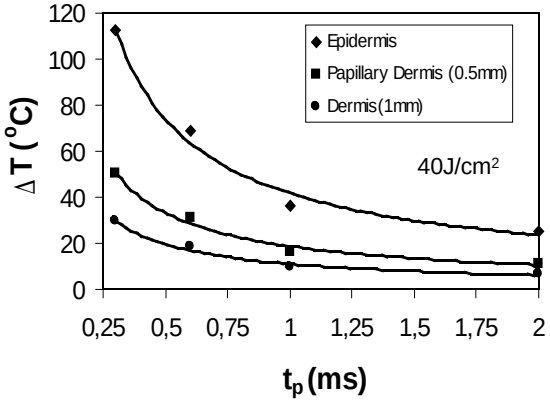

Fig. 7: Calculated fractional temperature increase (ΔT) for different depths within the skin (Fitzpatrick type I-II), as a function of the Nd:YAG pulse duration (40J/cm^2, 3 mm spotsize).

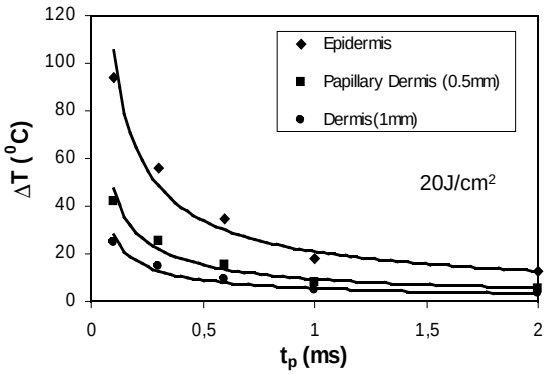

Fig. 8: Calculated fractional temperature increase (ΔT) for different depths within the skin (Fitzpatrick type I-II), as a function of the Nd:YAG pulse duration (20J/cm², 3 mm spotsize).

The thermal relaxation time of the deeper lying vascular targets can be obtained by observing the relaxation time of an infinite cylinder:

$$\tau = d^2/16\,\alpha \quad , \qquad (2)$$

giving thermal relaxation time for different blood vessel diameters as shown in Table 1. The FRAC3® treatment modality with pulse durations between 0.1 and 0.4 ms is therefore targeting vessels below 50 μm of size.

Vessel diameter (μm)	Thermal relaxation time (ms)
10	0.057
20	0.23
50	1.42

Table 1: Thermal relaxation time for the range of blood vessel diameters.

Self-induced temperature fractionality was observed also deeper within the skin, demonstrating the three-dimensionality of the effect. Figure 9 shows thermal images following Nd:YAG pulses as seen in-vitro on a skin cross section from a skin excised from a female human belly. Figure 9a shows a typical skin thermal image following a standard 20 msec long Nd:YAG pulse, and Fig.9 b shows the thermal image following a short duration 0.3ms Accelera pulse. Again, self induced temperature fractionality can be observed only following the illumination with the Accelera pulses.

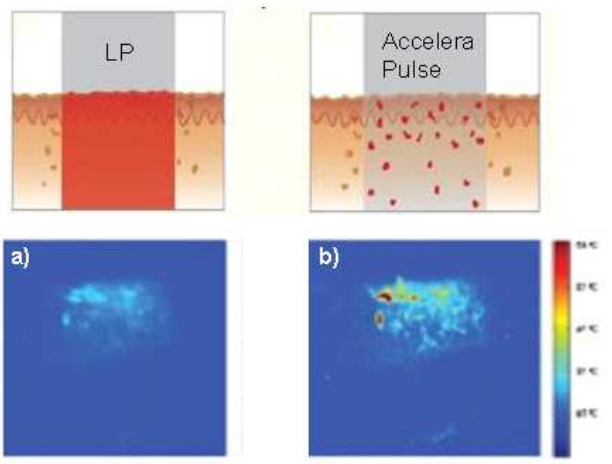

Fig. 9: Skin cross-section thermal images following Nd:YAG laser pulse with a duration of 20ms (a) and 0.3ms (b).

CLINICAL EXPERIENCE

Clinical results show the self-induced three-dimensional non-ablative Nd:YAG laser fractional treatment to be safe and effective alternative to more aggressive laser techniques [10,15]. Typical treatment parameters are 15-40 J/cm² at pulse durations of 0.1-0.4 ms. Photographic evaluations show improvement in erythema along with an associated improvement in skin quality [10]. The improvement in pore size, texture and color is attributed to the short pulse targeting of the microvasculature [11]. No side effects apart from transient erythema have been reported.

Ultra-structural analysis of patients treated with 0.3 ms Nd:YAG laser pulses has shown a decrease in overall collagen fiber diameter in the papillary dermis. This is consistent with the formation of new collagen [10,12]. The treatment stimulates new collagen production by producing localized thermal injury to the dermis that initiates a wound-healing response [12]. During wound healing, procollagen and type III collagen fibers are produced initially and have a small diameter. A decrease in collagen fiber diameter has therefore been associated with production of new collagen, which is thought to increase skin firmness and improve skin texture in patients after treatment [13]. The best results were obtained with patients below 50 years of age while older patients did not show a decrease in collagen fiber diameter [10].

SOE: SCANNER OPTIMIZED EFFICACY

One feature of the *FRAC3®* treatment modality is its requirement for relatively high energy and fluences at short pulse durations, meaning it is difficult to achieve with larger spot sizes. Yet manually aiming a small to medium spot size laser beam hundreds of times to cover a larger skin area can lead to uneven coverage

and can result in missed areas and excess heating due to pulse stacking. The laser must be placed with millimeter precision over the entire area, an impossible task as it is difficult to determine the treated area accurately.

SOE (Scanner Optimized Efficacy) technology eliminates these problems by utilizing computer-controlled laser scanner mirrors to automatically place the 3 mm spot size laser beam in a perfect non-sequential pattern [14,15].

SOE Technology provides fast, precise, consistent and comfortable *FRAC3*® laser treatments. It eliminates fatigue and provides consistency in treatments. SOE Technology is used to treat large areas of various sizes by quickly filling the entire area with uniform energy at high laser pulse power densities. The result is a safer, uniform laser treatment without hot spots and energy loss.

CONCLUSIONS

A novel, *FRAC3*® non-ablative fractional laser method is described, that produces a self-induced fractional thermal damage matrix within the skin tissues. The *FRAC3*® fractional thermal damage structure forms around the existing skin imperfections and inhomogeneities, and is not arbitrarily imposed on the skin by the external optics. This makes the method very effective and minimally invasive. Additional advantage of the *FRAC3*® approach when compared to the standard fractional techniques is that the resulting fractional damage islands are not limited to the two-dimensional column matrix but are distributed in a three-dimensional manner throughout the skin volume. In addition, no special optical device is needed, thus leading to enhanced cost effectiveness of the skin rejuvenation procedure as well.

The new *FRAC3*® laser method is the next step in improved laser skin rejuvenation procedures, with its efficacy, selectiveness, short healing time and cost effectiveness.

REFERENCES

1. M. Gorjan, L. Grad, M. Lukac., Three Dimensional Fractional Laser Skin Rejuvenation, IMCAS 2008 Abstracts Booklet, P28.
2. Manstein D, Herron GS, Sink RK, et al. Fractional photothermolysis: a new concept for cutaneous remodeling using microscopic patterns of thermal injury. *Lasers Surg Med* 2004; 34:426-38.
3. H. Nakagawa, O.T. Tan, J.A. Parish, Ultrastructure Changes in Human Skin after Exposure to a Pulsed Laser, J.Invest.Dermatol. 84: 396-400 (1985).
4. I.O. Svaasand, T.E. Milner, B. Anvari, L.T. Norvang, B.S. Tanenbaum, S. Kimel, M.W. Berns, J.S. Nelson, Epidermal Heating During Laser Induced Photothermolysis of Port Wine Stains: Modeling Melanosomal Heating after Dynamic Cooling the Skin Surface, Laser Interaction with Hard and Soft Tissue II, Porc.SPIE vol.2323: 366-377 (1995).
5. RR. Anderson, J.A. Parrish, Selective Photothermolysis-precise Microsurgery by Selective Absorption of Pulsed Radiation, Science 220:524-527 (1983).
6. B.C. Wilson and G. Adam. A Monte Carlo model of absorption and flux distributions of light in tissue. Med. Phys. 10, 824-830, 1983.
7. Anderson R, Parrish J., The optics of human skin, J Invest Dermatol. 1981; 88:13-19.
8. L. Grad, M. Lukac, Scientific evaluation of the VSP Nd:YAG laser for hair removal, J. Laser and Health Academy, Vol. 2007, No.1., www.laserandhealth.com
9. FRAC3 and Accelera modes are based on the Fotona d.d. (www.fotona.com) VSP (Variable Square Pulse) proprietary technology for the generation and control of laser pulses.
10. C.D. Schmults, R. Phelps, D.J. Goldberg, Nonablative Facial Remodeling, Arch Dermatol, Nov. 2004; 140: 1373-1376.
11. D. Groot, K. Smith, Non-Ablative Skin Therapy with CoolGlide Vantage Sub-Millisecond 1064 nm Laser Treatments, Altus Medical, October 2002, D0074 Rev. B.
12. R.A. Clark, Cutaneous Tissue Repair:Basic Biological Considerations, J.Am. Dermatol., 1985;13: 701-725.
13. R.A. Clark, Basics of Cutaneous Wound Repair, J. Dermatol. Surg.Oncol. 1993; 19:693-706.
14. Scanner Optimized Efficacy (SOE) is a Fotona d.d. (www.fotona.com) proprietary technology for prefectly covering large skin areas with optimally sized individual beam spots.
15. M. Lukac, L. Grad, Scanner Optimized Aesthetic Treatments with the VSP Nd:YAG Lasers, J. Cosmetic Laser Therapy, Vol. 10, No.2, June 2008.

