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New Skin Treatment Possibilities with PIANO Mode on an Nd:YAG Laser

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ABSTRACT

Non-ablative skin textural improvement is based on the theory of delivering a suitable packet of photo-thermal damage (coagulative and biostimulating) to dermal layers beneath a cooled epidermis. In this paper, a new Nd:YAG laser pulse duration modality is introduced which is perfectly suited for this purpose. This new, super long, PIANO modality, which extends the Nd:YAG pulse durations to the seconds regime, is much longer than the thermal relaxation time of the epidermis or any other skin structures, and does not cause high initial temperature peaks in the epidermis. It is therefore indicated for treatments where overall homogeneous, bulk heating of the dermis is desired. Based on the in-vivo study of the thermal effects of the PIANO mode on human skin, clinical protocol guidelines for laser skin remodeling, skin tightening and laser-assisted wound healing are developed. The PIANO modality may be of benefit also when considering treatments that combine the non-ablative Nd:YAG laser skin remodeling with the Er:YAG laser fractional skin resurfacing.

Key words: laser skin remodeling, scar prevention, wound healing, Nd:YAG laser, PIANO mode.

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I. INTRODUCTION

a) Selective photo-thermolysis

Since the invention of the laser, many types of laser sources have been studied and used as a means to improve skin appearance [1]. 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 the surrounding tissue. This approach is called "selective photothermolysis" [2]. Typically, however, the wavelengths that are highly absorbed in skin imperfections are also highly absorbed by non-target structures, for example, melanosomes [3] or hemoglobin-containing RBC [4]. Consequently, these wavelengths do not reach deeper lying targets (such as blood vessels or hair follicles), and can result in excessive damage to the epidermis and other healthy skin structures. The choice of wavelength is thus dictated not only by the need for good absorption of the laser in the treated skin structure, but also by the need to avoid unnecessary damage to the epidermis. For this reason, it is often better to select a laser wavelength that penetrates more deeply into the tissue, and then achieve selective tissue modification by adjusting the laser pulse duration to the thermal relaxation time of the targeted imperfection.

Among all non-ablative laser sources, the Nd:YAG laser holds the most prominent position. This is due to its long wavelength of 1064 nm, which in terms of absorption, lies in an optical window that allows light of this wavelength to penetrate deep into the skin, while its absorption in a target such as a blood vessel or a hair follicle is strong enough to affect the target (See Fig. 1) [5, 6].

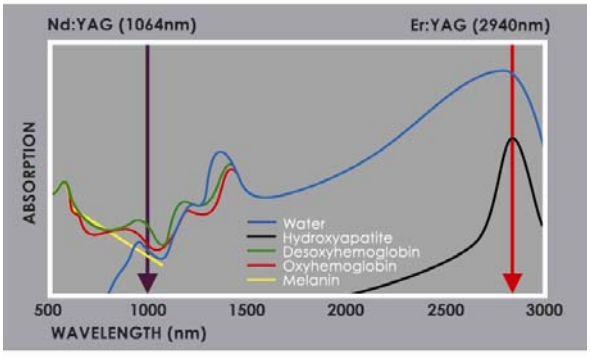

Fig. 1: Absorption coefficient in human tissues, μ_a as a function of laser wavelength. The absorption coefficient is at a minimum with the Nd:YAG laser wavelength (1.064 μm), and at a maximum with the Er:YAG laser wavelength (2.94 μm).

Besides the proper selection of the wavelength in order to illuminate a given tissue structure, the pulse duration must also be considered. Namely, the pulse

duration determines the heat source generated in the tissue since the heat diffusion process leads to temperature gradients in it. During a lengthy laser exposure most of the deposited heat will diffuse away from the target structure, resulting in nonspecific thermal damage to adjacent structures. Conversely, a laser pulse that is significantly shorter than the target thermal relaxation time TRT minimizes the time available for heat diffusion and confines the heating effect to the target structure, resulting in maximum temperature difference between the target and adjacent structures (see Fig. 2) [7]. Here, the relaxation time TRT represents the time interval in which the amplitude of a hypothetical temperature rise decreases by approximately a factor of two due to the diffusion of heat into surrounding tissue.

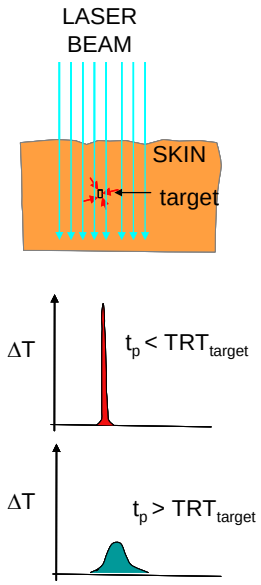

Fig. 2: With short laser pulsewidth ($t_p < TRT_{target}$), a small skin imperfection or a hair follicle experiences a high localized temperature increase ΔT, while with a longer laser pulsewidth ($t_p > TRT_{target}$), the local temperature increase is much smaller.

Figure 3 shows the dependence of the minimal size d of the skin target that can be selectively heated by a laser pulse of duration t_p. Confinement of laser energy within smaller structures requires progressively shorter pulse durations [8].

Using the relatively deeply penetrating Nd:YAG laser wavelength, and targeting skin imperfections by adjusting the laser pulse duration t_p to the cooling times of these imperfections, is the paradigm behind most of the Nd:YAG laser aesthetic procedures [6-8]. For this reason, aesthetic Nd:YAG laser systems cover a wide range of laser pulse durations, from nanoseconds (Q-switched mode) [9] to several hundred microseconds (FRAC3 mode) [8], and finally to several tens of milliseconds (LP or Long Pulse mode) [6-7] (See Fig. 4).

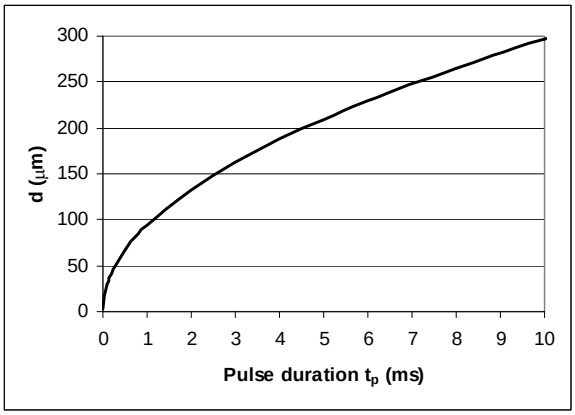

Fig. 3: Minimal size (d) of a skin structure that can be selectively heated by a laser pulse of duration t_p.

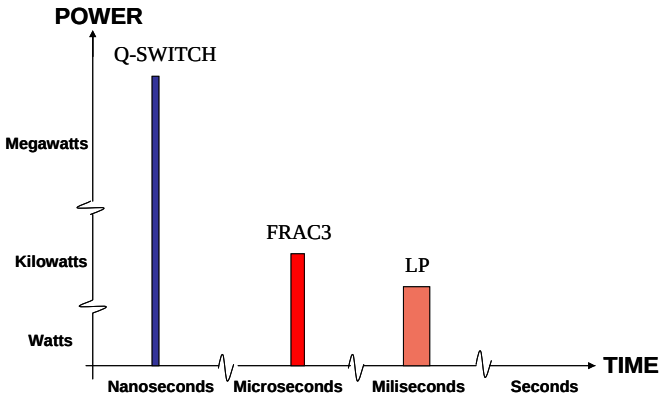

Fig. 4: Wide range of Nd:YAG pulse durations and instantaneous pulse powers.

All of the above pulse duration modes are used for selective photo-thermolysis procedures, with the optimal choice of the pulse duration depending on the size of the treated skin structure. The Q-switch pulses are preferably used for treating tattoos and pigmented lesions [9]. The FRAC3 pulses produce a three-dimensional fractional pattern in the epidermis and dermis, with damage islands located predominantly at the sites of miniscule aging skin imperfections [8].

And the duration of LP pulses is matched with the relaxation times of hair follicles and blood vessels [6-7].

b) Homogeneous photo-thermolysis with the new PIANO mode

Laser treatment is safest when a laser pulsewidth can be chosen that is longer than the thermal relaxation time, TRT_{epi} of the epidermis, but shorter than the TRT_{target} of the treated skin target. This

allows selective heat treatment of the target without overheating the epidermis.

A schematic presentation of the influence of laser pulsewidth on the temperature distribution within the skin is shown in Fig. 5 [7].

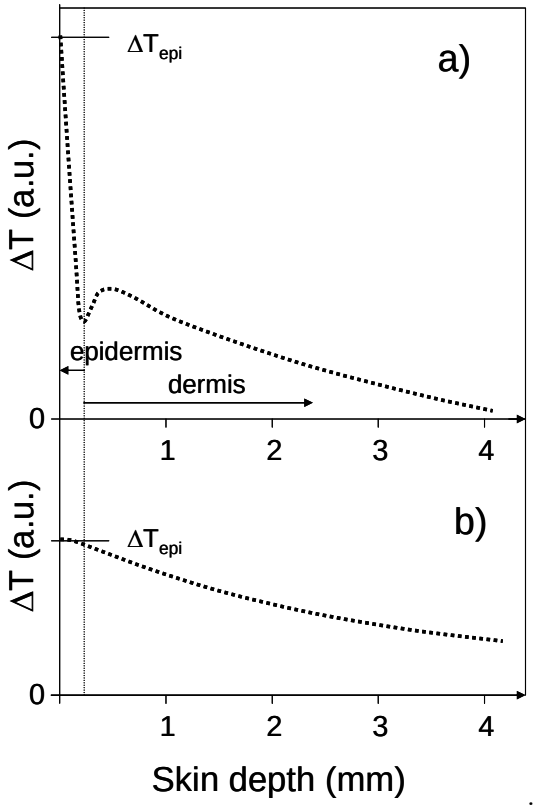

Fig. 5: Calculated temperature distribution immediately after a short Nd:YAG laser pulse with $t_p << TRT_{epi}$ (a), and after a long duration Nd:YAG laser pulse with $t_p >> TRT_{epi}$ (b). For skin types I-II, the temperature increase of epidermis is approximately 3 x higher when short pulse durations are used [7].

For short laser pulsewidths ($t_p << TRT_{epi}$), the distribution of the temperature increase (ΔT) closely follows the absorption characteristics of the epidermis and dermis. Due to the high concentration of melanosomes in the epidermis, laser absorption, and consequently ΔT is highest in the approximately 100 μm thick epidermal layer, while the temperature increase in the dermis is more moderate (Fig. 5a).

For long laser pulsewidths ($t_p >> TRT_{epi}$), the temperature distribution is dominated by the thermal diffusion process. Since there is a sufficient time for the epidermis to share the absorbed heat with dermis through heat diffusion, the temperature distribution does not have a pronounced peak in the epidermal layer (Fig. 5 b). Long pulse durations therefore result in a relatively homogeneous "bulk" heating of the skin.

In non-tanned, light skin photo-types, melanosomes are concentrated primarily in a d_{epi} =10 μm thick basal layer (typically located 50-100 μm below the skin surface) while in tanned, darker skin phototypes more melanin is distributed throughout the epidermis. As a result, the epidermal TRT can vary from less than 1 ms to over 100 ms [19]. In most cases, however, the thermal relaxation time of the epidermis is on the order of 25-100 ms. Figure 6 shows results of a recent study [7], where epidermal temperature decay curves were measured following an irradiation with a short duration (1 ms) Nd:YAG laser pulse.

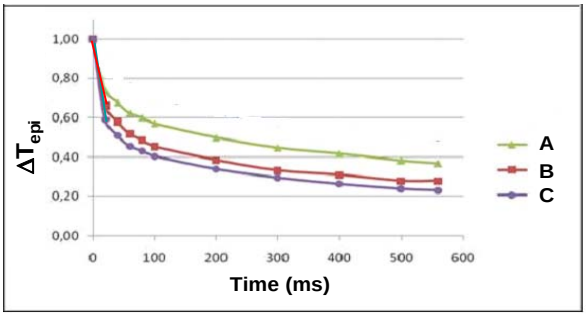

Fig. 6: Skin surface normalized temperature (T_{epi}) decay curves following a 1ms pulse duration Nd:YAG laser pulse for geographical skin types A (Europe), B (China, Egypt) and C (India, Japan) [7].

In Fig. 6, the initial fast decay lasts approximately 100 ms, and is caused by the diffusion mediated heat transfer from epidermis to dermis. This is followed by a slower decay that lasts several seconds. During this slower cooling process, the bulk skin looses heat due to its thermal contact with the ambient air and deeper body tissues.

Therefore, when no specific skin imperfections are targeted, and instead a non-selective heating, or "homogeneous photo-thermolysis" of the bulk dermis is desired, Nd:YAG laser pulsewidths considerably longer than 100 ms are preferable. Longer pulsewidths ensure that the dermis is homogeneously heated up while the epidermis is spared from unnecessary thermal damage.

Most of the presently available aesthetic Nd:YAG laser systems do not operate at pulsewidths much longer than 100 ms. They have been developed for the selective photo-thermolysis of skin imperfections that requires pulsewidths that match relatively short thermal relaxation times of the targeted skin imperfections. There are, however, several important

indications for homogeneous photo-thermolysis that require "super long" laser pulsewidths. These indications include photo-thermal skin remodeling, skin tightening and surgical scar prevention.

Recently, a new Nd:YAG laser pulse duration modality has been developed that is intended specifically for homogeneous, photo-thermolysis treatments [10]. This new, PIANO modality extends the Nd:YAG pulse durations to the seconds regime (0.3 - 60 s), and reduces treatment pulse powers to a less invasive watts regime (up to 80 W) (See Fig. 7).

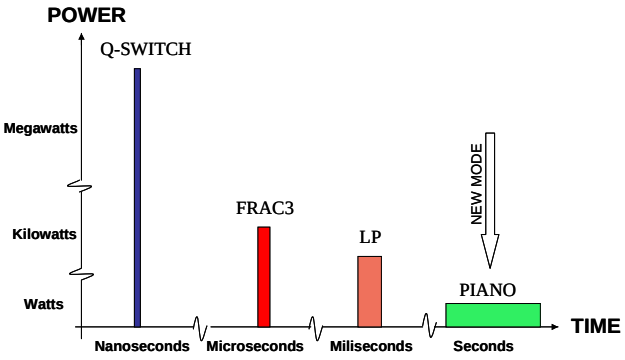

Fig. 7: The new "super long pulse" PIANO mode enables pulse durations in the seconds regime, and exhibits less intensive pulse powers of several Watts.

The duration of the PIANO mode is much longer than the thermal relaxation time of the epidermis. This is therefore the safest mode for reaching deeper lying skin tissues, with minimal thermal effect on the epidermis. The PIANO mode pulsed durations are also longer than the relaxation times of any other skin structures, such as hair follicles or blood vessels. The PIANO modality is thus indicated for overall homogeneous, bulk heating of the dermis, justifying its name (piano: adjective meaning soft or smooth [11]).

In this paper, we report on an in-vivo study of the latest PIANO mode in terms of its thermal effect on human skin. Based on the obtained results and previously published clinical data, clinical protocol guidelines were developed for the following homogeneous photo-thermolysis treatments: a) skin remodeling, b) dual wavelength skin resurfacing, and c) wound healing and scar prevention.

II. MATERIALS AND METHODS

The Nd:YAG laser used in the study was a Fotona XP Dynamis laser system with R33 and R34 non-contact handpieces with spotsize diameters from 2-20 mm (See Fig. 8). The laser was upgraded to the new PIANO (t_p=0.3 - 60 s) mode. The diode laser used in the experiments was a Fotona XD-2 810 nm diode laser system.

Fig. 8: Fotona XP Dynamis Nd:YAG laser system with PIANO mode capabilities, used in the study [15].

A thermal imager, model Sagem Matis, operating in the 3-5 μm spectral range, was fixed in position above the skin surface and focused on the treatment site (Fig. 9). Thermal camera images were taken at 20 ms intervals starting at approximately 2.5 ms following a laser pulse. The image exposure time was approximately 2 ms. The imager sensor detects thermal light emitted from the surface and also some from the subsurface as light of wavelengths 3-5 μm has a penetration depth of about 50 μm in the tissue. The measured temperatures therefore represented a weighted average of the skin temperature within the penetration depth of the detected thermal radiation.

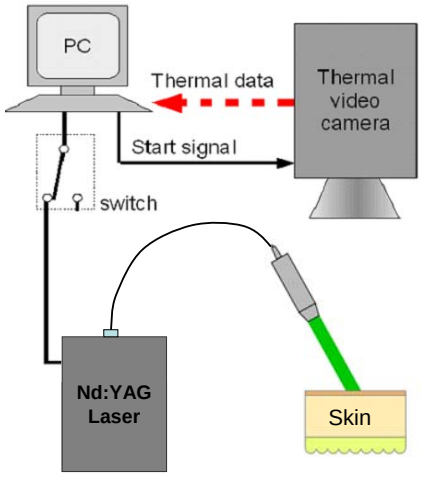

Fig. 9: Experimental set-up.

Skin surface measurements of the temperature distribution following Nd:YAG and diode laser irradiations were performed in-vivo on female patients' of skin type II.

III. RESULTS

Figure 10 shows the measured temperature evolution on the hand skin (thenar web between thumb and forefinger) following Nd:YAG laser radiation with a 1.5 s PIANO pulse (Super Long Pulse), and a 20 ms LP pulse (Long Pulse), for the same pulse fluence of 35 J/cm².

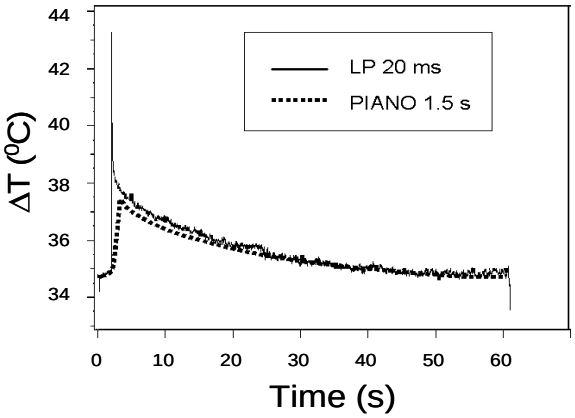

Fig. 10: Measured temperature evolution of dorsal hand skin following irradiation with the Nd:YAG laser PIANO (1.5 s) pulse mode (red line), and LP (20 ms) pulse mode. The laser pulse fluence of 35 J/cm² was the same for both pulse duration modes.

As expected from the calculations (See Fig. 5), the measured peak epidermal temperature is approximately 3 x higher with the 20 ms Nd:YAG laser pulse. After approximately 0.5 s when the epidermal temperature gets equalized with the temperature of the lower lying dermis the surface skin temperature has approximately the same temperature decay dependence, irregardless of the Nd:YAG pulse duration. This demonstrates that with the PIANO mode, the same temperatures of the bulk dermis as with shorter pulse durations, are achieved. However, with the PIANO mode, high initial temperature peaks in the epidermis are completely avoided.

Figure 11 shows the measured dependence of the measured peak skin surface (hand skin between thumb and forefinger) temperature on the illuminating PIANO pulse fluence.

The hand skin (thenar web) temperature increase was observed to follow an approximately linear dependence on the PIANO laser pulse fluence, independent of the pulse duration, in the range of 0.5 to 5 s.

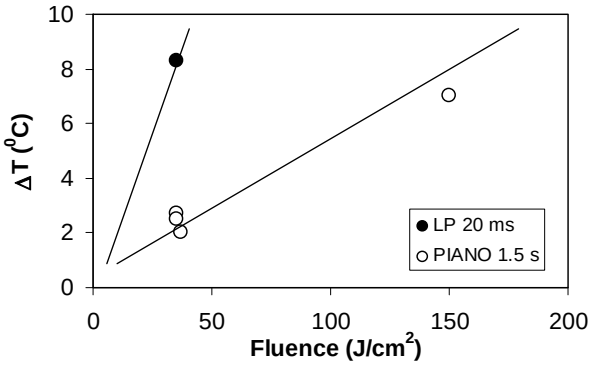

Fig. 11: Measured dependence of the peak skin surface temperature increase for the PIANO mode Nd:YAG laser illumination of 1.5 s pulse duration. For comparison, a temperature increase with a shorter, 20 ms Nd:YAG pulse is also shown. Spot sizes were in the range of 10-20 mm. Diagonal lines in the chart are only a visual aid.

As expected, the skin temperature increase depended on the body location. Table 1 shows the measured temperature increase on the facial cheek, beard and forehead. For comparison, the temperature increase on the hand skin is also shown.

Table 1: Skin temperature increase following a PIANO pulse (1.5 s) illumination on different parts of the body. Measurements were performed on a female patient of skin type II.

	ΔT (at 35 J/cm²)	ΔT/Fluence
cheek	7.6 °C	0.22 °C cm²/J
beard	7.1 °C	0.20 °C cm²/J
forehead	12.7 °C	0.36 °C cm²/J
hand	2.7 °C	0.05 °C cm²/J

Typically, PIANO laser treatments are painless since the epidermis does not reach as high temperatures as is the case with shorter pulses. However, this is not the case when a laser treatment is performed on the skin area where there is an underlying larger size blood vessel. In such a case, the temperature of the blood vessel and of the neighboring tissue can substantially increase, resulting in the feeling of pain.

It is interesting to note that the presence of an underlying blood vessel can be detected from the temporal evolution of the skin surface temperature. As an example, Fig. 12 shows the temporal evolution of the skin surface temperature on dorsal hand skin where an underlying blood vessel was present.

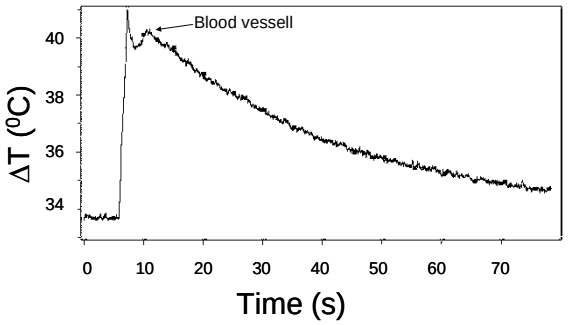

Fig. 12: Temporal evolution of dorsal hand skin in the presence of an underlying blood vessel following an Nd:YAG PIANO pulse (1.5 s, 150 J/cm^2). Heat diffusion from the underlying heated vessel results in a second skin surface temperature peak, with the time delay depending on the depth of the vessel within the skin.

The underlying, more absorbant blood vessel gets heated up during the Nd:YAG laser irradiation. Following the laser pulse, the heat diffuses away from the hot blood vessel in all directions. With a certain time delay, this results in another temperature peak within the epidermis.

IV. DISCUSSION

a) PIANO skin remodeling

Beginning in our 20s, the effects of aging start to become visible in skin. Genetically programmed chronologic aging causes biochemical changes in collagen and elastin, the connective tissues that give skin its firmness and elasticity. As skin becomes less elastic, it also becomes drier. Underlying fat padding begins to disappear. With the loss of underlying support by fat padding and connective tissues, the skin begins to sag. It looks less supple, and wrinkles form. Occurring simultaneously with genetically programmed aging, the process of photoaging is also taking place. Photoaging is the effect of chronic and excessive sun exposure on the skin. Cigarette smoking also contributes to aging effects.

Laser remodeling is a procedure inducing controlled thermal injury to the collagen in the dermis which leads to subsequent collagen remodeling while preserving the epidermis [13]. As dermal collagen heals and remodels under an undamaged outer layer, the skin tightens and smoothes, thus improving its appearance.

The aim of the controlled, sub-coagulative laser heating of the dermis is to induce a heat shock response (HSR). HSR is defined as temporary changes in cellular metabolism. These changes are rapid and transient, and are characterized by the production of a small family of proteins termed the heat shock proteins (HSP). A controlled temperature increase and duration of the thermal surge within the dermal tissue is crucial to obtaining a suitable photo-thermal biologic response. Heating the collagen to a higher temperature than required to achieve a controlled heat shock would denature and damage the collagen beyond the point of contraction. There is a logarithmic relationship between duration and temperature increase that is required to achieve HSP expression. For heat shocks that last several seconds, HSP hyper-expression occurs at relatively low sub-coagulative skin temperatures, between 50 and 55 ^{0}C. For shorter thermal surges the temperature elevations must be considerably higher [13].

Photo-thermal remodeling has been successfully achieved, reaching a critical sub-coagulative temperature, with many different lasers, radiofrequency devices and polychromatic high-intensity light sources [16-47]. Since for many of the successfully used devices, the pulse duration was on the order of seconds, this demonstrates that deep, homogeneous heating of the dermis plays an important role in photo-thermally activated neo-collagenesis. It has been demonstrated, however, that with extremely short and high power laser sources (Q-switched and possibly FRAC3 Nd:YAG), an additional, photo-mechanical inflammatory effect comes into play [48]. The photo-thermal, homogeneous photo thermolysis promotes the formation of collagen type I, while the photo-mechanical, selective photo-thermolysis promotes the synthesis of collagen type III more effectively.

There are several advantages of Nd:YAG skin remodeling compared to using other devices. First, the absorption in the epidermis is smaller compared to other light-based devices. Second, the depth of the thermal surge within the skin is completely controlled, and there is no danger of accidentally overheating deeper lying tissue, as is the case with radiofrequency devices. Third, the depth of the thermal surge can be adjusted to a certain extent by varying the laser spotsize. And fourth, the energy is delivered into the skin with energy-controlled pulses of adjustable duration.

Nd:YAG laser-induced collagen remodeling has been studied extensively. Goldberg first reported the effect of non-ablative laser skin resurfacing with the Q-switched 1,064-nm neodymium–yttrium–aluminum garnet (Nd:YAG) laser in 1997 [16]. They found that the Q-switched 1,064-nm Nd:YAG laser provides satisfactory clinical results with no post-operative morbidity in the treatment of periocular and perioral rhytides. Later Goldberg performed a series of clinical studies with histologic examinations to prove the collagen remodeling effects of a Q-switched 1,064-nm

Nd:YAG laser [17,18]. A long-pulsed 1,064-nm Nd:YAG laser with its low scattering coefficient and weak absorption by water and melanin has also been shown to improve the appearance of coarse wrinkles and fine lines and to reduce skin laxity [32–36]. In a recent systematic study by Liu et al on a Kunming (KM) mouse model in vivo, the following results were obtained with a long-pulsed (0.3 ms) Nd:YAG laser at 30 J/cm2 and 6 mm spotsize [48]. Eight weeks after the Nd:YAG laser treatments, an increase in collagen type I (46.4+-4.6%) and collagen type III (15.9+-2.9%) were observed. Fibroblast proliferation correlated with collagen synthesis. The collagen was observed to begin to increase 3 weeks after the laser treatments, and the increasing trend could persist for 5 weeks, reaching its greatest level of effect in 4 weeks, a result similar to human clinical trials [48].

It is important to note that when only photo-thermal, bulk heating of the dermis is indicated, the pulsewidth at which the Nd:YAG laser energy is delivered to the skin does not have a significant effect on the overall temporal evolution of the dermal temperature. No matter whether the laser energy is delivered in 0.3 ms or 500 ms, the dermal temperature will quickly, within a hundred milliseconds, equalize with the temperature of the epidermis, and then slowly cool down with its long relaxation time of approximately ten seconds. The laser-induced heat shock of the bulk dermis therefore always lasts for several seconds, irregardless of the pulsewidth of the heating Nd:YAG laser source. Shorter pulsewidths have a significant effect only on the bulk epidermis, which in the initial heating phase may experience a higher, short duration thermal surge due to its higher absorption compared to the dermis. For "heat shocking" of the dermis using Nd:YAG laser radiation, it is therefore preferable to use super long PIANO pulses that achieve approximately the same overall heat shock effect on the dermis while sparing the epidermis from the unnecessary thermal damage.

Based on the results of the previous and present study, we recommend the following starting treatment parameters for skin remodeling (Table 2).

Table 2: Starting treatment parameters for PIANO mode Nd:YAG skin remodeling. Parameters are for the Fotona Dynamis Nd:YAG laser system.

SKIN REMODELING	
SOURCE: Nd:YAG	HANDPIECE: R33, R34
MODE: PIANO	
Pulse duration: 0.5 - 1.5 s	
Fluence: 35 – 65 J/cm^2	
Spotsize: 9 – 20 mm	

b) PIANO skin tightening

The 1064 nm laser has been shown to be an excellent wavelength to contract collagen and initiate new collagen formation, resulting in what is commonly referred to as "skin tightening" [70-72]. The advantages of using the Nd:YAG to treat for skin laxity include its speed of treatment (due to large treatment spot sizes and high repetition rate), fluence levels (for sufficient heat deposition), low melanin absorption (to avoid epidermal injury) and cost (treatments can be delivered quickly, safely and without disposables). Since skin tightening belongs to the skin remodeling category it is a result of sufficient heat deposition to contract and reformulate collagen.

The before and after pictures after the Nd:YAG skin tightening treatments show a remarkable improvement in the patient's skin color, tone, wrinkles and laxity, with minimal patient discomfort. Complications from the laser treatment were minimal including erythema and swelling from a few hours, to a few days post treatment. No other complications were seen. The treatment included minimal discomfort and high patient satisfaction [70].

Since a PIANO mode has been introduced only recently, the longest, until recently available pulse durations (50 ms) were used for skin tightening. Using a so called Taylor technique, [70] a relatively low single pulse fluence of 18 J/cm^2 was applied in order to avoid unnecessary epidermal damage. The required dose of heat deposition was then achieved by repeatedly treating areas 3-4 times. The clinical endpoint of the laser treatment was a surface skin temperature of 40-45ºC as measured by IR thermometry.

As observed also by Taylor, [72] it is less important how quickly the necessary heat dose is introduced into the skin than ensuring sufficient energy has been delivered. The PIANO mode is thus perfectly suited for performing skin tightening treatments. Instead of treating a particular skin area 3-4 times with 50 ms pulses of low (18 J/cmm^2) pulse fluence, the PIANO mode enables the doctor to tread the skin within one pass only, using a higher fluence of 35-65 J/cm^2 (See Table 2).

c) PIANO wound healing and scar prevention

The cosmetic outcome of surgical scars is of paramount importance to physicians and patients undergoing surgery. Considerable efforts are therefore made to improve scar appearance and, more importantly, to avoid the development of postsurgical hypertrophic scars or keloids. Prevention of hypertrophic scars is obviously preferable to treatment

and implies using a therapy aimed at reducing their incidence [49, 50].

Recently, a significant improvement in the appearance of a surgical scar was obtained by performing a LASH (Laser-Assisted Skin Healing) treatment immediately after surgery. Initially, Capon et al [61] 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. This finding was later confirmed in a pilot study of five patients. Laser-treated scar portions demonstrated better quality compared with untreated scar portions [62]. A study was also reported that showed 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 [63]. Finally, a prospective comparative clinical study was made to evaluate the use of an 810 nm diode laser system to accelerate and improve the healing process in surgical scars immediately after skin closure [69]. 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/cm2) 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. Twenty-two patients were treated using a high dose (80–130 J/cm2) and 8 patients with a low dose (<80 J/cm2). 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 the control. Three patients treated with higher doses (115 J/cm2) 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/cm2), there was no significant difference in the treated segment versus the control segment. No side effects were observed. In conclusion, this prospective comparative trial demonstrated that an 810-nm diode laser treatment, performed immediately after surgery, can improve the appearance of a surgical scar. The dose plays a significant role in scar improvement and must be well controlled.

The above LASH (Laser-Assisted Skin Healing) technique induces a temperature elevation in the skin which modifies the wound-healing process. As in laser remodeling, 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 [64]. Heat shock response (in particular HSP70 synthesis) is responsible for the release and production of growth factors (in particular via the modification of the TGFb profile), thus increasing the rate of cell proliferation and the speed of collagen production, hence improving scar aspects [65, 66]. Several studies have demonstrated that the most significant difference between normal tissue and scar tissue is in the orientation of the fibrosis matrix [67, 68].

In order to compare the thermal effects of the 810 nm diode laser, used in the LASH technique, with the PIANO mode Nd:YAG laser, we have made measurements of hand skin (thenar web between thumb and forefinger) surface temperature following illumination with a diode laser (810nm). Results are shown in Fig. 13.

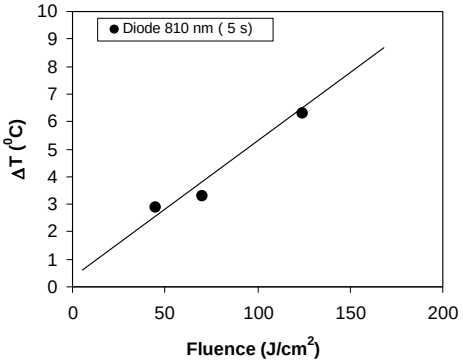

Fig. 13: Measured dependence of the peak skin surface temperature increase for diode (810 nm) laser illumination with a duration of 5 s. Spot size was 6 mm. The diagonal line in the chart is only a visual aid.

When comparing the results obtained with the diode laser (Fig. 13) and the PIANO mode Nd:YAG laser (See Fig. 11) we can conclude that the PIANO mode Nd:YAG laser is suitable for the LASH technique, with similar fluences required to induce the recommended temperature elevation in the skin, and thus to modify the wound-healing process.

Based on the results of the previous and present study, we recommend the following starting treatment parameters for Nd:YAG laser-wound healing and scar prevention (Table 3).

Table 3: Starting treatment parameters for PIANO mode Nd:YAG promotion of wound healing and scar prevention. Parameters are for the Fotona Dynamis Nd:YAG laser system.

WOUND HEALING/SCAR PREVENTION	
SOURCE: Nd:YAG	HANDPIECE: R33, R34
MODE: PIANO	
Pulse duration: 5 s	
Fluence: 90 – 110 J/cm^2	
Spotsize: 3 – 20 mm	

V. CONCLUSIONS

In conclusion, a new Nd:YAG laser pulse duration modality was introduced. This new, super long, PIANO modality extends the Nd:YAG pulse durations to the seconds regime. The duration of the PIANO mode is much longer than the thermal relaxation time of the epidermis, or any other skin structures, such as hair follicles or blood vessels. As a result, the PIANO modality does not cause high initial temperature peaks in the epidermis. For "heat shocking" of the dermis using Nd:YAG laser radiation, it is therefore preferable to use super long PIANO pulses that achieve approximately the same overall heat shock effect on the dermis while sparing the epidermis from the unnecessary thermal damage. The PIANO modality is thus perfectly indicated for treatments where overall homogeneous, bulk heating of the dermis is desired.

Clinical protocol guidelines for skin remodeling, skin tightening and wound healing were developed, based on previously published clinical studies and our in-vivo study of the thermal effects of the PIANO mode on human skin.

The PIANO modality may be of benefit also when considering treatments that combine the non-ablative Nd:YAG laser skin remodeling with the Er:YAG laser fractional skin resurfacing [73-74].

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