Determination of Optimal Parameters for Laser for Nonablative Remodeling with a 1.54 μm Er:Glass Laser: A Dose-Response Study

Jean Luc Levy, MD,* Regis Besson, MD,* and Serge Mordon, PhD†

*Centre Laser Dermatologique, Marseille, France, and †INSERM, Lille, France

BACKGROUND. Nonablative subsurface heating is a challenge for medical laser companies. Among the different lasers proposed today, the erbium-glass (Er:glass) laser combined with contact cooling could be an alternative for nonablative remodeling.

OBJECTIVE. To investigate the risk of side effects according to the quality of cooling and number of pulses.

METHODS. A clinical evaluation was performed on 10 patients using an Er:glass laser (1.54 μm) with contact sapphire cooling handpiece (+5°C). Periorbital and perioral areas were treated with a number of pulses increasing gradually from three to eight for a total energy of 24–64 J/cm². The presence or absence of swelling, crust, blister, and erythema were graded at 7 days. At 3 months postoperatively, hypopigmentation, hyperpigmentation, textural changes, and scars were evaluated clinically.

RESULTS. Periorbital and perioral areas respond differently to the number of pulses defining a "safe" clinical threshold. The periorbital site is very sensitive to dermal heating and efficacy of contact cooling; the anatomic features of this body location may explain these differences.

CONCLUSION. Selective dermal heating can be achieved with an Er:glass laser coupled with a contact cooling handpiece. The quality of the contact cooling and the number of pulses appear to be important parameters for safety and reproducible clinical results.

J.L. LEVY, MD, R. BESSON, MD, AND S. MORDON, MD HAVE INDICATED NO SIGNIFICANT INTEREST WITH COMMERCIAL SUPPORTERS.

IN THE CONTEXT of photoaging, wrinkles of the face can be treated by many methods, including injections of substances with and without resorption, peeling, and resurfacing with CO_2 or Er:YAG lasers. Yet none of these methods conclusively prevent wrinkle formation; they can only be considered rejuvenating for multiple wrinkling due to photoaging.

The chemical, mechanical, and thermal resurfacing techniques ensure epidermal renewal with reorientation of the collagen fibers in the superficial dermis. Because of the thermal effect, laser techniques require experienced operators. Also, these resurfacing techniques have socially discomforting effects: a 7-day social exclusion, a 6-week erythema, hyper-, and hypopigmentation, and risks of infection. A system that can treat wrinkles in a procedure that does not have these drawbacks and which can be applied in other indications had been introduced to the medical market for photoaging treatment.

Nonablative skin resurfacing (subsurfacing) with lasers is obtained by heating papillary dermis with epidermis protection. The level of dermal injury in nonablative techniques is controlled by the synchronization of surface cooling and heating. Heat is generated within the zone of optical penetration by direct absorption of laser energy. Absorption is the primary event that allows a laser or other light source to cause a potentially therapeutic (or damaging) effect on a tissue. Without absorption, there is no energy transfer to the tissue, and the tissue is left unaffected by the light. Scattering of light occurs in highly structured media such as skin. Due to fluctuations in the refractive index of the media, the propagation of light into the tissue is modified and the scattering affects "where" the absorption will occur, usually reducing the penetration of light into the tissue. Heating decreases with tissue depth as absorption and scattering attenuate the incident beam. Based on the absorption and effective scattering coefficients of the skin, the optical penetration depth can be determined with the following equation:[1]

$$\delta = 1(\sqrt{3}\mu_a(\mu_a + \mu_s')\,.$$

The optical window of 1.2 and 1.8 μm seems well suited for nonablative remodeling since the optical penetration depth is limited to the upper dermis.[2–5] Table 1 shows the absorption and reduced scattering coefficients for skin in this specific window. Thus the

Address correspondence and reprint requests to: Jean Luc Levy, MD, Centre Laser Dermatologique, 3 Bd Lord Duveen, 13008 Marseille, France, or e-mail: laserder@worldnet.fr.

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Table 1. Absorption and Scattering Coefficients and Optical Penetration Depth in Skin as a Function of Wavelength (Calculation Using Data Provided by Troy and Thennadil[10])

Wavelength (μm)	*Absorption coefficient μ_a (cm^{-1})*	*Effective scattering coefficient μ_s (cm^{-1})*	*Optical penetration depth δ (mm) in skin*
1.32	1	14	1.49
1.45	16	12	0.27
1.54	10	11	0.40

bulk of tissue heating, if not counteracted by surface cooling, will occur superficially. The instantaneous "pilling up" of energy at or near the surface favors the heating front. With surface cooling produced by a cooled contact window, the rate of cooling depends primarily on the temperature gradient between the skin and cooling window, and on the surface contact heat transfer coefficient.[1]

Epidermis protection is illustrated in Figure 1. In a combination with a cooling device, the epidermal temperature is limited to a maximum of 55°C.[6] These calculations are supported by an experimental study performed on animals. Using a 1.54 μm laser in a single-pulse mode, the results reported by Mordon et al.,[7] following an experimental evaluation in vivo, have clearly shown that the thermal damage could be restricted to less than 400 μm in depth while using a single pulse and a low fluence (26 J/cm^2).[7]

The thermal damage depends on the total energy. Depending of the skin thickness, fractionating the total fluence into pulse trains could be required in order to increase the damaged zone while preserving the epidermis. Several studies have indicated that controlling the depth of thermal damage can be obtained by controlling the number of pulses in the pulse train. Muccini et al.[8] demonstrated that using an optical train of repeated pulses is far superior to a single-pulse mode to confine the heat damage inside the tissue. However, the delay between two consecutive pulses must carefully determined in order to increase the temperature inside the upper dermis while protecting the epidermis with cooling. In order to achieve this goal, the delay between two pulses should be three to five times the thermal relaxation time (TRT) of the target, based on the following equation:

$$TRT = d^2/(k/\alpha),$$

where d is the thickness of the heated volume, approximately 0.025 cm; α is the thermal diffusivity of the dermis, 2×10^{-3} cm^2/sec; and k is a geometrical factor that is equal to 4.

As a result of these calculations and this experimental study, it appears clear that the duration of the pulse and the number of pulses with a 300- (3 Hz) to 500-msec (2 Hz) interval (three to five times the TRT) are in fact determinants in obtaining optimal thermal action in the solar-damaged zone of the upper dermis.

This study aimed to determine the maximum number of pulses needed to safely treat two areas with an Er:glass 1.54 μm laser. These two areas—the periorbital region and the upper lip—are different in the thickness of the dermis and epidermis and the type of subcutaneous tissue.[9] This step consisted of evaluating the optimal set parameters for these two different areas and the possible side effects.

Materials and Methods

Laser

The Er:glass 1.54 μm Aramis-Quantel laser (Quantel Medical, Clermont-Ferrand, France) is a new medical laser devoted to dermatologic treatment. This is a flashlamp-pumped system. The wavelength is obtained from a specific co-doped Yb-Er:phosphate glass material, optimized for high-efficiency pumping absorption. The laser head is optimized to reduce pump radiation absorption by water and it is based on high-diffusion materials. The design of the laser cavity is simple, assuming high efficiency and good stability. It works in normal mode, delivering up to 5 J in 3 msec. It can work either in single-shot mode or in a pulse train mode with a repetition rate of up to 3 Hz. The beam is delivered by an optic fiber. An aiming bean is provided by a red laser diode. Internal cooling avoids water connections and only a standard power

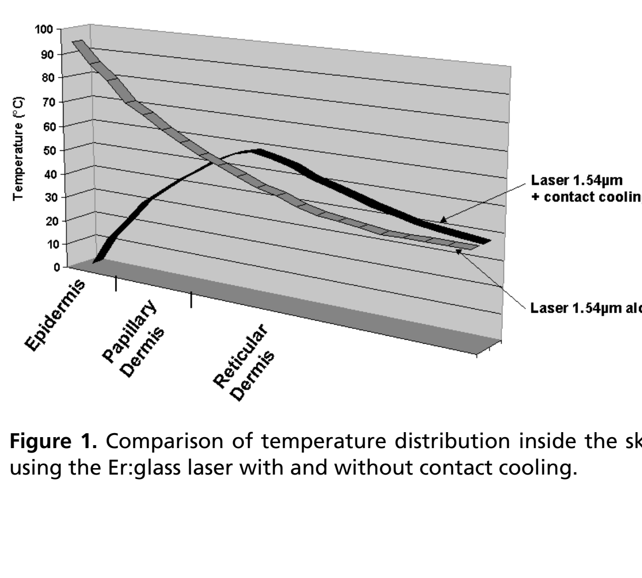

Figure 1. Comparison of temperature distribution inside the skin using the Er:glass laser with and without contact cooling.

outlet (10 A) is required. The system is compact, monitored by a microprocessor that provides high reliability.

Cooling System

The skin was cooled using the Constans Handpiece (Quantel Medical), a cryo-sapphire-tip handpiece which is in direct contact with the skin. The cooling is obtained thanks to a purified tetrafluoroethane cryogen circulating in the tip. This handpiece includes a real-time temperature monitor at the sapphire for immediate feedback. The handpiece is connected to an electronic unit, allowing temperature stability within 1°C during treatment. The original handpiece had a 2 cm viewing window (Figure 2A). For this study the laser was tuned to 8 J/cm^2/pulse (2 Hz repetition rate). Three (24 J/cm^2) to eight pulses (64 J/cm^2) were applied on the periorbital and perioral areas. For both areas, a 4 mm spot handpiece was used, connected to a cooling system. The cooling temperature was set at +5°C and the contact maintained for at least 2 seconds before firing the laser. During the protocol, a cooled handpiece with an 8 mm viewing window was also evaluated (Figure 2B).

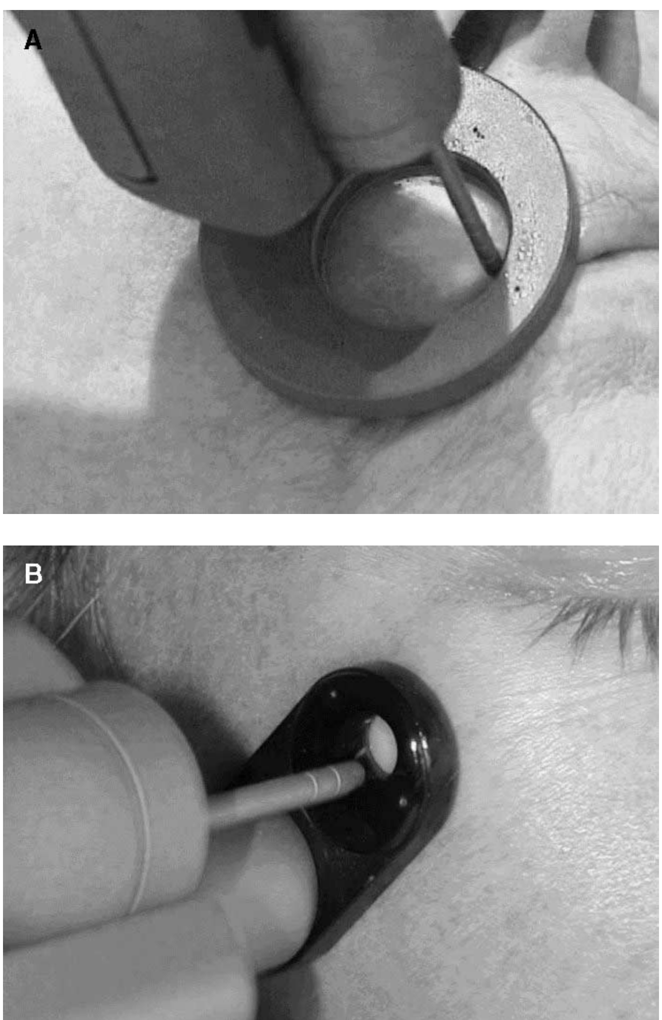

Figure 2. Handpieces used for contact cooling: A) 2 cm and B) 8 mm diameter viewing area.

Table 2. Skin Type Distribution (10 Patients)

Skin type	I	II	III	IV
Number of patients	1	3	4	2

Patients

Ten patients were included in this study, ranging in age from 37 to 62 years (mean 42 years). Characteristics of photoaging lines and wrinkles in all patients were similar, varying from skin type I to IV. All patients showed lines at rest and wrinkling was seen at the moment of smiling and/or with mimics. Four of the 10 patients had skin type IV (Table 2).

Three periorbital and three perioral sites were irradiated on each patient. All of the patients signed a consent form, which was approved by the local ethical committee. Before treatment, the area to be treated was prepared with skin cleanser only. The treatments were performed without any kind of anaesthesia.

Evaluation Methodology

Photographs were obtained in standardized conditions (professional photographer, lighting, frame) at day 0, before treatment, and 1 week later. Patients were graded for the presence of erythema, swelling, crusts, and blistering at day 7 in relations with the number of pulses. Side effects at 3 months were assessed.

Results

Table 3 shows the distribution of side effects with the number of laser pulses observed at 1 week. On the perioral area, these side effects were clearly due to the number of pulses, with thermal injury causing pitted necrosis with crusts. At 3 months, pitted scars were still present. In zones without thermal injury, all the subjects showed a final wound healing at 3 months without textural changes.

Table 3. Distribution of Side Effects with Number of Laser Pulses Observed at 1 week.

	No. of pulses							
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
Perioral	5N	5N	5N	5N	4N 1E	2N 3E	3N 1S 1C	No Tx
Periorbital	5N	5N	1N 3E 1C	1S 3C 1B	2S 2C 1B	No Tx	No Tx	No Tx

N, no epidermal effects; E, erythema; S, swelling; B, blistering; C, crusting.

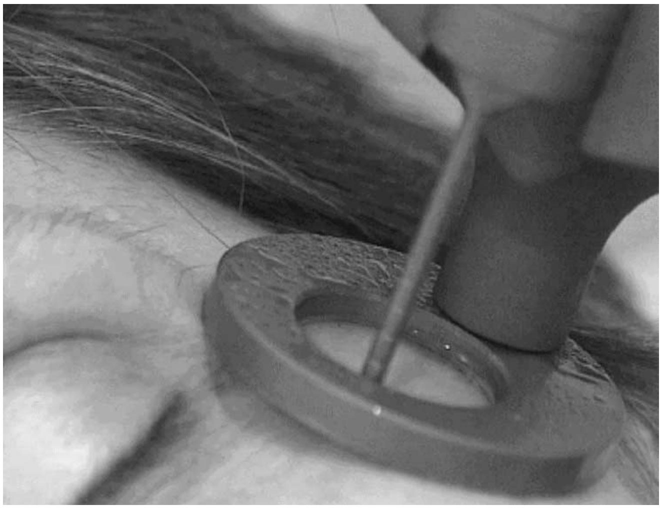

Figure 3. Periorbital zone during treatment showing that contact cooling was not optimal due to the size of the 2 cm optical window, limiting the efficacy of cooling.

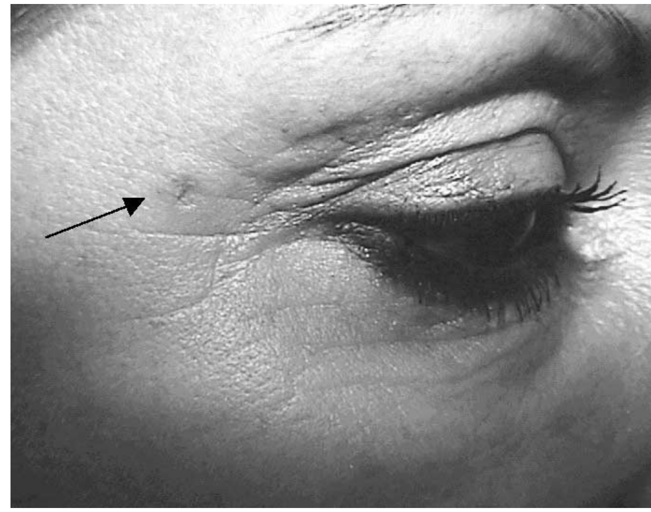

Figure 4. Erythema at 7 days after laser treatment (four pulses) of the periorbital area.

On the periorbital area, in some subjects immediate whitening occurred after three to four pulses (Figure 4). The temporal area of the crow's feet is concave. These side effects were mainly due to the absence of contact of the cooled window of the handpiece with the 2 cm viewing window (Figure 3) in the area of treatment. The maximum duration of swelling, crusts, blisters, and erythema was 9, 7, 3, and 17 days, respectively. Our evaluation of side effects at 3 months is shown in Table 4.

Discussion

There is only one study using the 1.54 μm laser published in the literature. This study was performed by Ross et al.[1] Postauricular sites were treated with different fluences (2–6 J/cm^2) per pulse. Irradiations were performed with a 5 mm spot size. The minimum fluence was 16 J/cm^2 (eight pulses of 2 J/cm^2), the maximum fluence 146 J/cm^2 (48 pulses of 3 J/cm^2). A cooled sapphire window was placed in contact with the skin. The cooling system was set to −10°C. A 2-second precooling period was designed into the control software of the laser. Immediate whitening and scarring was observed at ≥60 J/cm^2. For pulse energy-pulse number combinations that did not result in immediate epidermal whitening, there was erythema and edema that persisted no longer than 2 weeks. At sites without gross epidermal necrosis due to overdosage, epidermal preservation and slight tinctorial changes in collagen staining were observed in a band 400–1300 μm (40 pulses) deep.

Of interest is that on the perioral areas, where the cooling was efficient, a side effect was observed for seven pulses (56 J/cm^2) beginning with an erythema at five pulses. This observation is in accordance with Ross et al.,[1] where immediate whitening and scarring were observed at ≥60 J/cm^2 for skin having a similar thickness (Table 5).

On the periorbital area, the side effects observed in our study were mainly caused by inefficient cooling

Table 4. Final Physician Assessment at 3 Months

Side effects	Hypopigmentation	Hyperpigmentation	Textural changes	Pitted scars
Number	0	2	2	3

Table 5. Parameters Used by Ross et al.[1] and in This Clinical Study

	Energy/ pulse (mJ)	*Pulse duration (msec)*	*No. of pulses*	*Spot diameter (mm)*	*Fluence range (J/cm^2)*	*Cooling*	*No. of passes*	*Frequency (Hz)*
Ross et al.	400–1200	1 ms	4–40	5	16–146	Contact −10°C; precooling 2 seconds	1–2	8
This study	1000	5 ms	3–10	4	24–80	Contact +5°C; precooling 2 seconds	1	2

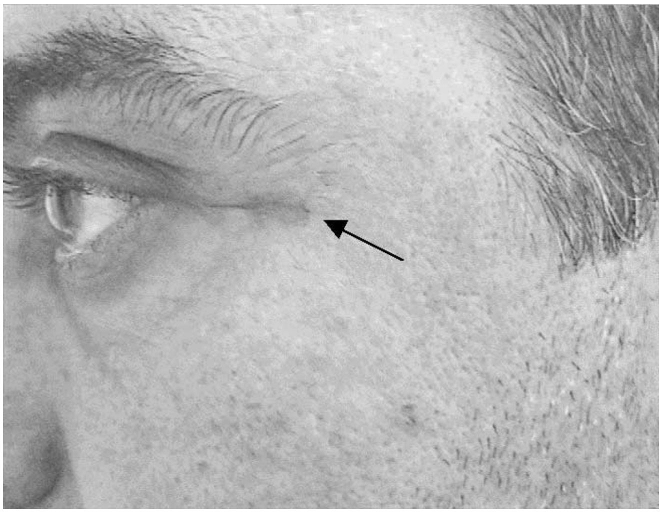

Figure 5. Hyperpigmentation at 3 months after laser treatment (four pulses) of the periorbital area.

(Figure 5). The too-large viewing window (2 cm) of the handpiece leads sometimes to the loss of contact of the cooling handpiece with the skin, and consequently inefficient cooling. This important observation has led to the development of a cooling handpiece with an 8 mm viewing window. Clinical evaluations performed later demonstrated that the problem of contact with the skin has finally been solved (data not shown). The periorbital area has thinner skin, and our evaluation has demonstrated that the total fluence should be reduced to 20–30 J/cm^2. We observe too that the bony zones are painful and may cause scar formation by thermal confinement of a dermal heating. This could be due to a lack of cooling in the dermis. No histology was performed, but this clinical evaluation has clearly demonstrated that the optimal parameters are three pulses (24 J/cm^2) for the periorbital area and five pulses (40 J/cm^2) for the perioral area.

Conclusion

Our study, in accordance with that published by Ross et al.,[1] confirms that the 1.54 μm wavelength combined with contact cooling can be used for nonablative remodeling. This clinical evaluation demonstrates that cooling associated to pulse train emission must be combined to confine the heat to the upper dermis. In order to avoid a temperature build-up, and consequently overheating, a sufficient delay between two pulses (ideally three to five TRT) should be carefully selected. This study clearly demonstrates that when using a 1.54 μm laser, applied to the perioral or a similar area in terms of skin thickness, the fluence must stay below 60 J/cm^2 in order to spare the epidermis. For thinner skins, the total fluence applied should be reduced to 20–30 J/cm^2. The quality of contact cooling, especially in curved and fine skin with poor fatty subcutaneous tissue, is essential in order to protect the epidermis. This study has determined the optimal number of pulses for each area in order to obtain safety with this new medical laser: three for the periorbital area and five for the perioral area. Further studies will evaluate the clinical efficacy as a function of the number of sessions.

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