
Treatment of Pigmented Hypertrophic Scars with the 585 nm Pulsed Dye Laser and the 532 nm Frequency-Doubled Nd:YAG Laser in the Q-Switched and Variable Pulse Modes: A Comparative Study

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BACKGROUND. Pigmented hypertrophic scars are a difficult condition to treat. They may result from traumatic injuries or from surgical and cosmetic procedures. The 585 nm flashlamp-pumped pulsed dye laser (FLPDL) has been used to treat this condition, with significant improvement of varying degrees. It remains to be determined whether other laser modalities may have a similar or even greater success in the treatment of pigmented hypertrophic scars.

OBJECTIVE. To determine the efficacy of the 532 nm frequency-doubled Nd:YAG laser in the treatment of pigmented hypertrophic scars as compared to the 585 nm FLPDL.

METHODS. Six patients with pigmented hypertrophic scars and skin phototypes II–IV were chosen. A scar was selected for treatment in each patient and divided into four equal 2 cm segments. Three segments were each treated with a different laser modality and one was left untreated to serve as the control. A 585 nm FLPDL was used with an energy of 3.5 J, a pulse duration of 450 μ sec, and a 10 mm spot size. A 532 nm Q-switched frequency-doubled Nd:YAG laser was set to an energy of 2.8 J, a 10-nsec pulse, and a 3 mm spot size. The same 532 nm laser was set to the variable pulse mode to treat a 2 cm scar segment, with an energy of 9.5 J, a 10-msec pulse, and a 4 mm spot size. An average of 3.3 treatments were performed on each scar segment, at intervals of 4–6 weeks and long-term follow-up at 22

weeks. Treatment outcome was graded by a blind observer using the Vancouver General Hospital (VGH) Burn Scar Assessment Scale. A SigmaStat *t*-test was used to determine the statistical significance of the values obtained.

RESULTS. Treatment of pigmented hypertrophic scars with the 532 nm Q-switched Nd:YAG laser led to a significant improvement of 38% in the VGH scores when compared to baseline ($P = .005$). The 585 nm FLPDL also had a favorable effect on the scars, with an average improvement of 36.1% in the VGH scores. There was no significant difference noted between the outcome of treatment with either of these two lasers. Treatment with the 532 nm variable pulse Nd:YAG laser led to a 19% improvement in the VGH scores of scars, which did not differ significantly from the 16.1% improvement observed in control scars on the last follow-up visit. No side effects or complications from treatment were noted or reported during the course of the study. At the conclusion of the study, five of six patients chose the segment treated with the 532 nm Q-switched Nd:YAG laser as the best segment overall.

CONCLUSION. The 532 nm Q-switched Nd:YAG laser and the 585 nm FLPDL offer comparable favorable results in the treatment of pigmented hypertrophic scars. The 532 nm Q-switched Nd:YAG laser may be preferred by patients particularly distressed by the dark color of their scars.

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SCARS ARE the end result of the process of wound healing, where many hormonal and cellular mechanisms act in synchrony.¹ These interactions will determine the specific color, size, and texture of the scar.² Wound healing may be divided into several consecutive and overlapping phases: inflammation, granula-

tion tissue formation, and extracellular matrix (ECM) formation with remodeling.

During the inflammatory phase, the injury to blood vessels leads to the activation of platelets and extravasation of blood components. Activated platelets release chemoattractants for neutrophils and macrophages. Early on, neutrophils rid the injured tissue of bacteria, and are later replaced by monocytes, which are transformed into macrophages in the tissue. Not uncommonly, healing may take place with postinflammatory

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hyperpigmentation and/or permanence of erythema and telangiectasia. However, there is scarce histologic data on pigmented scars. It is presently unknown whether the hyperpigmentation is due to increased numbers of basal layer melanosomes or melanocyte hyperplasia.³

Granulation tissue begins to form approximately 5 days after injury. It is characterized by a loose connective tissue matrix containing fibroblasts, macrophages, and newly formed blood vessels. Macrophages release cytokines that are responsible for attracting fibroblasts to the wound site, as well as promoting their proliferation and synthesis of collagen and ECM components. This connective tissue matrix provides the scaffolding through which all the participating cells and new blood vessel sprouts will migrate. Similarly angiogenesis is stimulated by cytokines, such as fibroblast-derived growth factor (FGF). Conversely, a crucial point during this phase of wound healing is the regression of capillary beds once the angiogenic stimuli are removed.² Failure of this process to take place may result in permanently erythematous or telangiectatic scars.³ In addition, persistence of capillary beds in the evolving wound may provide increased nutrition to the fibrous tissue of the scar and contribute to its exaggerated size/thickness.

Lastly, ECM formation and tissue remodeling are characterized by the deposition of collagen, fibronectin, hyaluronic acid, and proteoglycans. Collagen fiber deposition and organization characterizes this last phase, and the wound gradually increases its tensile strength throughout the first year following tissue injury. If excessive deposition of collagen and/or failure of collagen turnover and lysis occurs, a thick, hypertrophic scar may form as a result. Hypertrophic scars, as opposed to keloids, remain within the confines of the original wound and may regress over time.⁴

Scars are a distressing and often difficult cosmetic condition to treat. This is particularly true when scars develop after cosmetic procedures and surgeries, or as a result of burns or traumatic injuries. Therefore scars that are pigmented and raised are also very unsightly and stigmatizing. Little information is currently available about the treatment of pigmented hypertrophic scars. Lasers, such as the 585 nm flashlamp-pumped pulsed dye laser (FLPDL), have been tried with success in the treatment of pigmented and hypertrophic scars.^{3,5,6} While this laser has provided significant improvement in the texture and color of the scars, complete disappearance of the pigmentation and/or thickness is not always achieved. Thus it remains to be proven whether other laser modalities may be more successful or equally effective in the treatment of pigmented hypertrophic scars.

Treatment with the 510 nm pulsed dye laser has led to improvement of postinflammatory hyperpigmentation in various conditions.⁷ On the other hand, the 532 nm frequency-doubled Nd:YAG laser is effective

in the treatment of myriad cutaneous pigmented lesions. These include lentigines and ephelides, café au lait macules, Becker's nevus, postinflammatory hyperpigmentation, melasma, and tattoos, especially those containing blue-black ink.⁸ The emitted wavelength of 532 nm is better absorbed by melanin than that of the 585 nm FLPDL, as melanin follows an exponentially decreasing curve of absorption with the highest absorption in the ultraviolet range (Figure 1). This may allow effective destruction of the pigment associated with scars. At the same time, the 532 nm wavelength is close to the 542 nm absorption band of oxyhemoglobin, and this could theoretically allow destruction of the vasculature associated with the hypertrophic scar. In our study we compare the efficacy of the 585 nm FLPDL and the 532 nm frequency-doubled Nd:YAG laser in the Q-switched and variable pulse modes in the treatment of pigmented hypertrophic scars.

Materials and Methods

Patient Selection

Eleven patients with pigmented hypertrophic scars were recruited from the various surgical clinics at Jackson Memorial Hospital. Adequate informed consent was obtained from all patients following the guidelines established by the Investigational Review Board. All 11 patients underwent the first laser treatment of scars, but only 6 presented for subsequent follow-up until completion of the study. This was due to a worsening medical condition unrelated to the laser treatment in four patients, and unavailability due to extended travel in one patient. The patients' ages ranged from 15 to 56 years. Table 1 illustrates the subjects' composition and includes Fitzpatrick skin phototypes, cause of scar, age of scar, previous treatments, location, and number of laser treatments received during the study.

Scar Assignment

The scars were divided into four equal and contiguous 2 cm segments. Three segments were each treated with a different laser modality each, and a fourth one was left untreated to

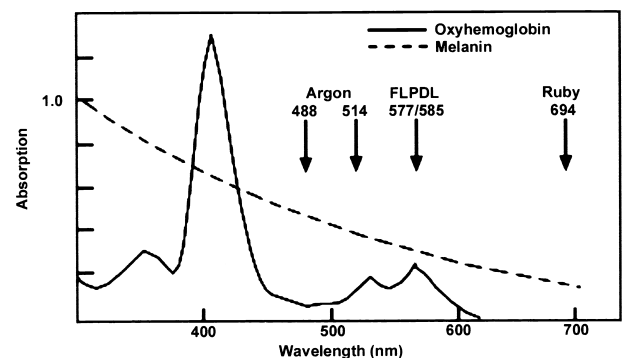


Figure 1. Absorption spectra of melanin and oxyhemoglobin.

Table 1. Characteristics of Pigmented Hypertrophic Scars

| Patient no. | Fitzpatrick skin type | Cause of scar | Previous treatment | Location | Age | No. of laser treatments |
|-------------|-----------------------|---------------|--|-----------------|-----------|-------------------------|
| 1 | IV | Excision | Intralesional steroids 6 months prior to laser | Chest | 5 years | 3 |
| 2 | III | Excision | None | Presternal | 2 years | 4 |
| 3 | III | Excision | None | Abdomen | 8 months | 3 |
| 4 | III | Abrasion | None | Inframandibular | 15 months | 3 |
| 5 | II | Excision | None | Breast | 16 months | 3 |
| 6 | III | Abrasion | None | Forehead | 3 months | 4 |

serve as a control site. Randomization of the scar segments for treatment with the various lasers was not achieved. This was due to the fact that a significant portion of the subjects with randomized scar segments did not return for follow-up after the first treatment. Therefore, for all subjects, segment A was treated with the Q-switched 532 nm Nd:YAG laser, segment B with the variable pulse 532 nm Nd:YAG laser, segment C served as the control, and segment D was treated with the 585 nm FLPDL.

Laser Treatment

The same laser settings were used for all patients during each treatment session. The 585 nm FLPDL was set to an energy of 3.5 J, with a pulse duration of 450 μ sec and delivered through a 10 mm spot size. There was an approximate 10% overlap of laser spots. No anesthesia was required by patients prior to treatment.

Two other 2 cm segments were treated with a 532 nm frequency-doubled Nd:YAG laser using two different modes of pulsing the energy delivered. The Nd:YAG laser was used in the Q-switched mode with an energy of 2.8 J, a 10-nsec pulse, and a 3 mm spot size. In the variable pulse mode the settings included an energy of 9.5 J, a 10-msec pulse, and a

4-mm spot size. The patients did not need anesthesia and tolerated the treatment well.

The patients were instructed to avoid rubbing or friction of the treated sites with clothing or during daily activities. They were instructed to apply a petrolatum ointment daily and to observe strict sun avoidance. Treatment sessions took place every 4–6 weeks, with patients receiving an average of 3.3 treatments to each scar segment. The mean long-term follow-up after the first treatment was 20 weeks, ranging from 18 to 22 weeks. Pictures were taken on the initial visit, and before and after treatment during each follow-up visit.

Evaluation of Treatment Outcome

Treatment outcome was graded using a modified Vancouver General Hospital (VGH) Burn Scar Assessment Scale (Table 2). This scale assigns ascending numeric values to the various characteristics of a scar, depending on the degree of pigmentation, vascularity, pliability, and height (or depression). Scores using this scale range from a minimum of 0 to a maximum of 13 for the thickest, most darkly pigmented and erythematous scars.

The values obtained by a blind observer on the initial and last follow-up visits were computed and presented in Table

Table 2. VGH Burn Scar Assessment Scale

| Parameter | Rating | Description |
|--------------|----------------|--|
| Pigmentation | 0 | Hypopigmentation |
| | 1, normal | Color closely resembles the color over the rest of one's body |
| | 2 | Hyperpigmentation |
| Vascularity | 0, normal | Color closely resembles the color over the rest of one's body |
| | 1, pink | A slight increase in local blood supply |
| | 2, red | A significant increase in the local blood supply |
| | 3, purple | Excessive local blood supply |
| Pliability | 0, normal | Normal pliability |
| | 1, supple | Flexible with minimal resistance |
| | 2, yielding | Giving way to pressure; offering moderate resistance |
| | 3, firm | Solid, inflexible unit, not easily moved, resistant to manual pressure |
| | 4, banding | Ropelike tissue that blanches with extension of scar; does not limit range of motion |
| Height | 5, contracture | Permanent shortening of scar producing deformity or distortion; limits range of motion |
| | 0, normal | Flat |
| | 1, <2 mm | |
| | 2, <5 mm | |
| | 3, >5 mm | |

Table 3. VGH Burn Scar Assessment Scale Values Before and After Laser Treatment, with Corresponding Percent Change (%Δ)^a

| Patient | Nd: YAG Q-Switched (Pre) treatment | Nd:YAG Q-Switched (Post) treatment | %Δ Nd:YAG Q-Switched | Nd:YAG Variable Pulse (Pre) treatment | Nd: YAG Variable Pulse (Post) treatment | %Δ Nd:YAG Variable Pulse | Control Initial Visit | Control Last Follow-Up | %Δ Control | FLPDL (Pre) treatment | FLPDL (Post) treatment | %Δ FLPDL |
|---------|------------------------------------|------------------------------------|----------------------|---------------------------------------|---|--------------------------|-----------------------|------------------------|------------|-----------------------|------------------------|----------|
| 1 | 8 | 4 | -50 | 8 | 6 | -25 | 8 | 7 | -12 | 9 | 6 | -33 |
| 2 | 9 | 5 | -45 | 7 | 5 | -28 | 6 | 5 | -16 | 9 | 5 | -45 |
| 3 | 9 | 5 | -44 | 9 | 8 | -11 | 9 | 8 | -11 | 9 | 5 | -44 |
| 4 | 5 | 3 | -40 | 4 | 3 | -25 | 4 | 3 | -25 | 4 | 3 | -25 |
| 5 | 6 | 4 | -33 | 5 | 5 | 0 | 5 | 5 | 0 | 5 | 4 | -25 |
| 6 | 6 | 5 | -16 | 4 | 3 | -25 | 3 | 2 | -33 | 4 | 2 | -50 |

^a Negative values for percent change (ie, -%Δ) indicate improvement in the VGH score of scars.

3. At the conclusion of the study the patients were asked to evaluate each scar segment and determine which one had improved the most in terms of color and thickness.

Statistical Analysis

Student's *t*-test was performed using the SigmaStat program.

Results

Table 2 indicates the specific VGH scores for each scar segment before and after three to four laser treatments, with a mean follow-up period of 20 weeks. These are depicted in schematic form in the histograms presented in Figures 2 and 3.

Treatment of scars with the 532 nm Q-switched Nd:YAG laser significantly improved their VGH score from an average initial value of 7.16 to 4.33 after 3.3 laser treatments (*P* = .005). One hundred percent of patients responded to treatment, with an average improvement of 38%. In a similar fashion, all patients treated with the 585 nm FLPDL showed a favorable response. The VGH score of their scars decreased from a mean value of 6.66 pretreatment to 4.16 posttreatment, corresponding to an improvement of 36.3%. This

change in VGH scores did not appear to be statistically significant. However, no significant difference in outcome was noted between the 532 nm Q-switched Nd:YAG laser and the 585 nm FLPDL, indicating comparable results with these two laser modalities.

When compared to the control group, the scars treated with the 532 nm Q-switched Nd:YAG laser showed a much greater improvement in their color, pliability, and height (38% versus 16.1% for the control group, *P* = .010). The scars treated with the 585 nm FLPDL also significantly improved these parameters as compared to the control group (36.3% versus 16.1%, *P* = .009).

The site treated with the 532 nm Q-switched laser almost invariably developed transient swelling and erythema immediately after treatment. Mild purpura developed at the 585 nm FLPDL treatment site of all patients in the study. The purpura was transient and lasted approximately 5 days.

Of all laser modalities, treatment with the 532 nm laser resulted in the least appreciable change, with average VGH scores of 6.16 pretreatment and 5.0 posttreatment. This is equivalent to an overall 19% improvement in scar texture and color. These findings did not differ much from those encountered in untreated control scar segments. The latter underwent a

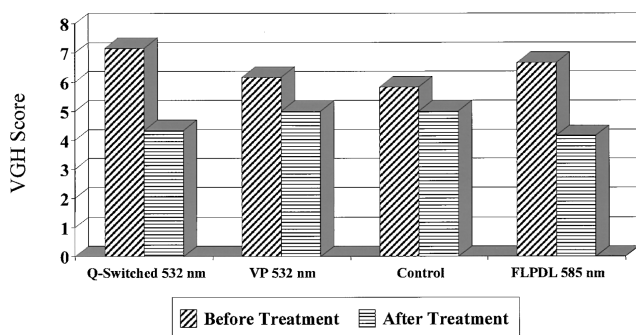


Figure 2. Average VGH scores for scars before and after laser treatment. (Q-switched 532 nm: Q-switched frequency-doubled Nd:YAG laser; VP 532 nm: variable pulse frequency-doubled Nd:YAG laser; FLPDL 585 nm: 585 nm flashlamp-pumped pulsed dye laser.)

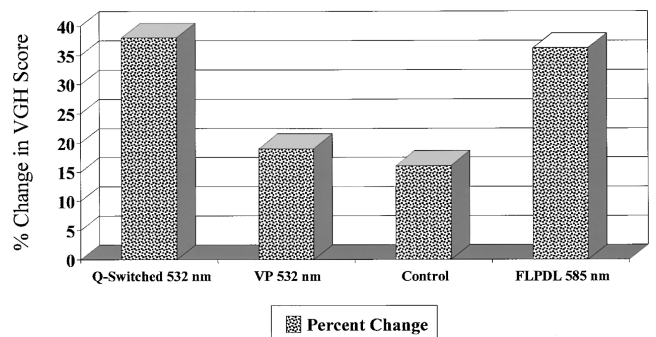


Figure 3. Average percentage change in the VGH burn scar scores before and after treatment with each laser modality. (Refer to legend in Figure 2.)

change in the VGH scores from 5.83 pretreatment to 5.0 posttreatment, equivalent to a 16.1% improvement. In both the 532 nm laser-treated and control groups only 83% of patients showed a response to treatment. No unfavorable effects or complications were noted with these or any of the other two lasers. The segments treated with the Q-switched 532 nm Nd:YAG laser and the 585 nm FLPDL showed the most appreciable improvement in color and thickness.

At the conclusion of the study all patients were asked which scar segment they thought had improved the most, taking into account the change in color and thickness/pliability of the scar. Five of six patients rated the segment treated with the 532 nm Q-switched frequency-doubled Nd:YAG laser as the best segment overall.

Discussion

The characteristics of scars must be taken into account before an appropriate treatment is chosen. Scars that are hypertrophic and pigmented may respond favorably to treatment with the 532 nm Q-switched Nd:YAG laser or the 585 nm FLPDL, as our results indicate. It may be postulated that laser wavelengths that target oxyhemoglobin will selectively destroy the vascular support of hypertrophic scars, and those with wavelengths selectively absorbed by melanin will help lighten their color. In the case of oxyhemoglobin (HbO₂), there is a peak absorption band at 418 nm (the Soret absorption band), followed by less intense absorption bands at 542 and 577 nm. The absorption spectrum of melanin, on the other hand, follows an exponentially decreasing curve from the ultraviolet end of the spectrum to the visible and infrared end (Figure 1).

Therefore a laser light with a wavelength approaching that of the 577 nm HbO₂ absorption peak will selectively target the blood vessels of hypertrophic and erythematous scars. In order to avoid thermal damage to the surrounding tissue, the microvessel size (approximately 10 μ m) and its thermal relaxation time (approximately 190 μ s) must be taken into account in order to choose the appropriate laser light intensity, pulse duration, and spot size.⁹ The 585 nm FLPDL, with a pulse duration of 450 μ sec and energies ranging from 6.0 to 7.5 J/cm delivered through a 5 or 7 mm spot size, has been used successfully in the treatment of erythematous hypertrophic scars.¹⁰ This laser modality has also been effective in the treatment of acne scars that are erythematous and hypertrophic.¹¹ As microvascular destruction takes place, there is significant ischemia of the laser-irradiated tissue, leading to decreased collagen synthesis. Overall the 585 nm FLPDL is effective in the treatment of a multitude of vascular lesions, including telangiectasias, capillary hemangiomas, and poikiloderma of Civatte.¹²

In turn, the 532 nm Q-switched Nd:YAG laser has a wavelength that is close to the 542 nm oxyhemoglobin absorption peak, while also being better absorbed by melanin than the 585 nm wavelength of the FLPDL (Figure 1). We postulate that this may have a twofold effect. First, although the shorter laser wavelength will penetrate only the superficial dermis, this is, however, where most vessels of hypertrophic and erythematous scars are found. Therefore, as the vascular supply of hypertrophic scars is destroyed, a regression in their thickness/size may be expected. Second, the 532 nm laser wavelength will be selectively absorbed by the melanocytes and/or melanosomes in the epidermis. This may have a favorable outcome on scar pigmentation. Also, the 10-nsec pulse duration is shorter than the thermal relaxation time of melanocytes and melanosomes (20–40 nsec and 1 μ sec, respectively), thus avoiding nonspecific thermal damage.

The rationale for also treating the hypertrophic scars with the variable pulse 532 nm Nd:YAG laser was to effectively destroy the blood vessels nurturing it. The 532 nm wavelength targets the 542 nm absorption band of oxyhemoglobin (Figure 1). In addition, the long pulse delivery of 10 msec was expected to cause slower injury of blood vessels, thus avoiding their rapid bursting and hemorrhage/purpura formation.

In our study, treatment of pigmented hypertrophic scars with the 532 nm Q-switched Nd:YAG laser and the 585 nm FLPDL showed comparable positive results. The percentage improvement in the VGH scores was 38 and 36.1, respectively. Of note, it should be mentioned that while the pigmentation and height/pliability of the scars were affected by both lasers, the 532 nm Q-switched Nd:YAG laser had a more pronounced effect on scar color, while the 585 nm FLPDL appears to have had a predominant effect on scar thickness and pliability.

When asked which laser treatment had improved the overall appearance of their scar the most, five of six patients chose the 532 nm Q-switched Nd:YAG laser. Although no significant differences were found between the effects of this laser and the 585 nm FLPDL on evaluation by the a blind observer, patients seemed to have been more pleased with the lightening of pigmentation obtained with the former. What may have initially appeared as postinflammatory hypopigmentation, led to a lighter scar color that was more pleasing to patients. This was universally the case, even for patients with darker skin phototypes.

Our findings indicate that in the treatment of pigmented hypertrophic scars both the 532 nm Q-switched Nd:YAG laser and the 585 nm FLPDL may have similar favorable results. The 532 nm Q-switched Nd:YAG laser may be preferentially used in patients particularly distressed by the dark color of their scars.

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