CLINICAL PAPER

NO. 1

Effective Treatment of Leg Veins with the GentleYAG™ Laser: A Theoretical Analysis

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Introduction

Leg telangiectasia and reticular veins are a common cosmetic concern, occurring in a large percentage of the population. Sclerotherapy has long been the accepted therapy for these anomalies. Sclerotherapy involves the insertion of a needle to inject a chemical sclerosing agent that causes damage and the eventual collapse of the wall of the blood vessel. While sclerotherapy remains the gold standard in the treatment of leg veins, recent studies have demonstrated improved clearances using different types of lasers.[1]

Many different lasers have been evaluated for treating these venous disorders. The pulsed dye laser and 532 nm green light lasers are the most popular laser technologies chosen for removal of vascular lesions. The high hemoglobin and melanin absorption coefficients at their wavelengths limit treatment efficacy for moderate-sized vessels (<1 mm).

Recently, there have been significant developments in laser treatment of larger diameter lesions (>1 mm). In particular, Nd:YAG laser systems have been gaining increasing popularity for treating blue venulectasias and reticular veins.

Candela has introduced its GentleYAG Nd:YAG laser, shown effective for hair removal due to its capability to deliver fluences up to 70 J/cm^2 through a 12 mm beam diameter during a 3 ms exposure.

The purpose of this paper is to discuss the scientific rationale of the GentleYAG for treatment of larger, deeper leg veins.

Selective Photothermolysis

Laser treatment of vascular lesions is based on the principle of selective photothermolysis.[2] By proper selection of laser system parameters, selective heating of vessels within the skin is possible while producing only minimal damage to the overlying epidermis and adjacent dermis. The basic elements of selective photothermolysis for the treatment of vascular anomalies are:

1. **Selective Absorption–**Laser energy should be preferentially absorbed by blood vessels and not by the overlying epidermis and adjacent dermis.
2. **Optical Penetration Depth (OPD)–**Laser energy should penetrate sufficiently deep to reach the larger and deeper situated vessels.
3. **Energy Deposition–**Laser energy at the vessel site should be sufficient to heat the vessels to the damaging temperature.
4. **Damage Confinement–**The exposure time of the laser energy should be less or equal to the thermal relaxation time of the vessels.
5. **Epidermal Cooling–**Although this is not a basic element of selective photothermolysis, it is an essential element in many laser therapies.

BASIC ELEMENTS	LASER PARAMETERS			
	Wavelength	Pulse Duration	Beam Diameter	Output Energy
Selective Absorption	X			
OPD	X		X	
Energy Deposition				X
Damage Confinement		X		

Table 1—Identifies the laser parameters that have the primary effects on selective photothermolysis basic elements. Laser parameters have to be selected appropriately to utilize selective photothermolysis effectively.

Selective Absorption—Wavelength

The GentleYAG is an Nd:YAG laser systems producing 1064 nm wavelength radiation. Figure 1 shows optical properties of blood, dermis, and epidermis, the skin constituent relevant to laser treatment of blood vessels, in the range of 650 to 1100 nm.[3] According to Figure 1, 1064 nm is optimal for treating larger beam diameter vessels because:

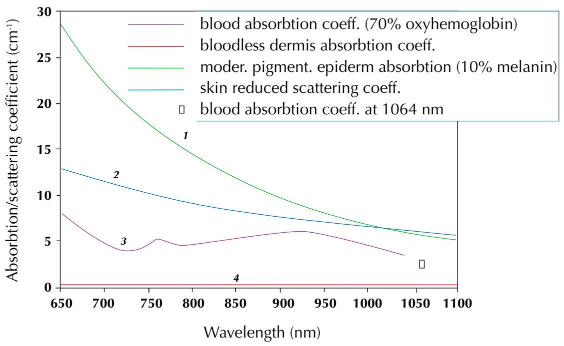

Figure 1—Optical properties of blood, dermis and epidermis in the range of 650-1000 nm.

—Melanin absorption is lower at 1064 nm than at shorter wavelengths, improving epidermal protection during treatment. Lower melanin absorption reduces the energy loss in the epidermis, increasing the overall efficiency. (Plot 1)

—Scattering within dermis is reduced at 1064 nm, allowing laser energy to penetrate and reach deeper vessels. (Plot 2)

—Selective targeting of blood vessels is possible due to greater absorption by blood than by the surrounding dermis. (Plots 3 and 4)

Although not apparent from Figure 1, blood absorption is low enough for a more uniform light distribution within the larger diameter vessel lumen.

At 1064 nm, the GentleYAG has the optimal wavelength to treat larger, deeper leg veins.

Optical Penetration Depth—Wavelength and Spot Size

The GentleYAG, like other Nd:YAG laser systems, has the optimal wavelength required for the treatment of larger, deeper blood vessels. However, laser wavelength is not the only factor affecting the safety and effectiveness of laser treatment of larger leg veins. A laser's entire parameter set must be considered.

Selective photothermolysis requires that the laser energy should penetrate sufficiently deep to reach the larger and deeper situated vessels. At 1064 nm, the optical penetration depth is determined by the optical properties of the tissue and by the incident laser beam diameter. The distributions of light fluence within dermis at 1064 nm laser irradiation with equal input fluences of 1 J/cm^2 were calculated by Monte Carlo simulations for 3, 6, 9, 12, and 15 mm beam diameters and are shown in Figure 2.[4,5] Figure 2 shows that larger beam diameters penetrate deeper than smaller beam diameters.

This deeper penetration translates into better vessel heating, which is shown in another Monte Carlo simulation. Figure 3 shows the local volumetric heat production within 1 mm diameter/1 mm deep, 2 mm/2 mm and 3 mm/2.5 mm blood vessels produced by three different beam diameters (3, 6, and 12 mm) with equal input fluences of 1 J/cm^2. The temperature rise produced by laser energy is proportional to the local volumetric heat production which is the product of the local fluence and absorption coefficient (μ_a). As beam diameter increases, a higher and more uniform heating of the blood vessel is achieved.

Figures 2 and 3 illustrate that larger beam diameters are more effective in reaching larger and deeper blood

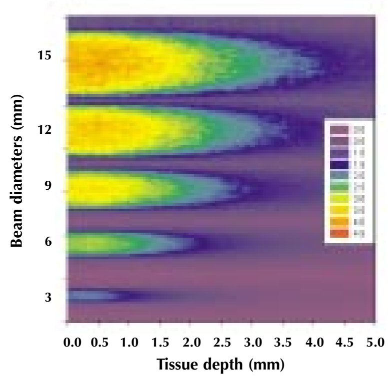

Figure 2—Laser fluence distribution within dermis for 3, 6, 9 , 12, and 15 mm beam diameters at 1064 nm.

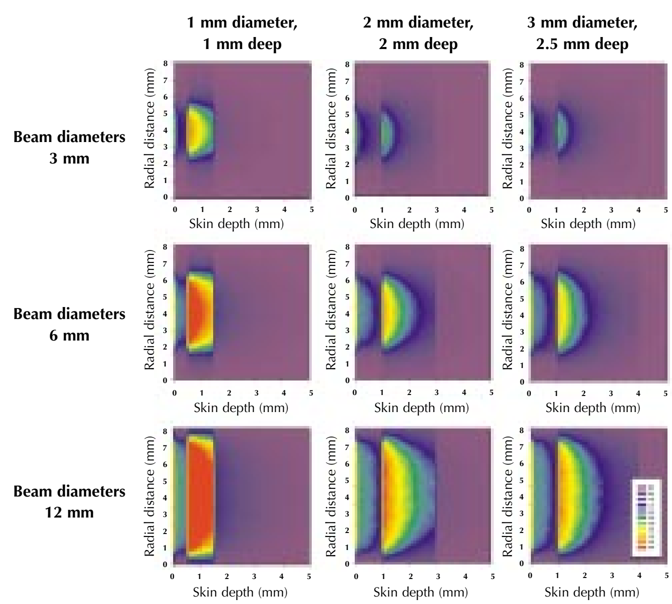

Figure 3—Local volumetric heat production within different blood vessels produced by 3, 6, and 12 mm beam diameters.

vessels. When considering the treatment of larger and deeper situated vessels, the appropriate beam diameter should also be considered.

With a 12 mm spot, the GentleYAG has the largest available spot size of any Nd:YAG laser. Consequently, GentleYAG can deliver its energy deeper than other smaller spot Nd:YAG lasers.

Energy Deposition—Fluence

Fluence is defined as energy divided by beam area with units of J/cm^2. Laser systems are characterized by the maximum fluence available at a given spot size and not just by the fluence alone. For example, a laser system capable of generating 80 J per pulse produces a fluence of 71 J/cm^2 when delivered through a 12 mm beam diameter. On the other hand, a laser system capable of generating only 20 J per pulse (which is 4 times weaker) can also produce a fluence of 71 J/cm^2 but through a beam diameter of 6 mm only. Because lasers with larger beam diameters penetrate deeper, the fluence of 70 J/cm^2 through a 12 mm beam diameter can treat larger and deeper blood vessels more effectively than 70 J/cm^2 delivered through a 6 mm beam diameter. What is really important is the fluence within the skin at the vessel site, not the delivered fluence at the skin surface.

The GentleYAG system is the most powerful Nd:YAG medical laser system capable of delivering 70 J/cm^2 in a 3 ms pulse duration through a 12 mm beam diameter.

Damage Confinement—Pulse Duration

The GentleYAG system emits laser pulses of 3 ms. A 3 ms pulse duration is advantageous for hair removal because it enables more effective treatment of finer, thinner hair far more effectively than longer pulse Nd:YAG lasers, and is also effective for vascular therapies. Other Nd:YAG systems offer longer pulse durations; and while increasing the pulse duration may improve skin tolerance, an efficient epidermal cooling method is a far more critical factor in epidermal protection. Vascular efficacy is not determined by epidermal protection but by how much energy is delivered to the leg vein without causing epidermal injury.

According to the principles of selective photothermolysis, laser pulse duration should be less or equal to the vessel thermal relaxation time because:

1. Maximum laser energy is deposited within the vessel, increasing procedure efficiency.
2. Thermal damage is confined only to the vessel, minimizing unwanted damage to surrounding tissue.

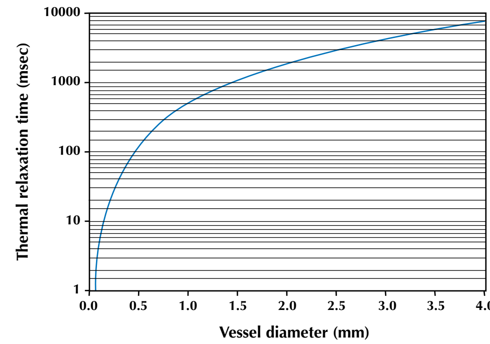

Figure 4—Thermal relaxation times for vessels ranging from 10 µm to 4 mm. (κ=1.3 *10^{-3} cm^2/sec).

Figure 4 shows the thermal relaxation times for vessel diameters ranging from 10 µm to 4 mm. According to this figure, 3 ms is the thermal relaxation of an 80 µm vessel. So, in the treatment larger veins (> 1 mm), a 3 ms pulse duration clearly meets the requirements of selective photothermolysis. Because the thermal relaxation times (TRTs) of larger blood vessels are so long, extending pulse durations does not materially improve energy absorption and does not modify temperature distribution within the vessels. This is substantiated in the data represented in Figure 5.

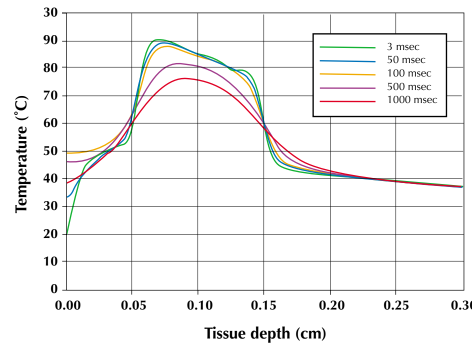

Figure 5—Temperature distribution inside a 1 mm diameter 1 mm depth vessel produced by 3, 50, 100, 500, and 1000 msec laser pulse durations.

Figure 5 was generated using Monte Carlo light simulations followed by heat transfer finite-difference modeling. This figure shows the temperature distribution inside a 1 mm diameter vessel located 1 mm within the skin produced by laser pulse durations ranging between 3 and 1000 ms with equal input fluences. The temperature distributions for 3 to 100 ms pulse duration are very close to each other.

Little is known about the effects of blood flow on heating blood vessels and its relationship to treatment efficacy. Blood velocity inside larger veins (several millimeters in diameter) can reach several cm/sec.[6] Therefore, heat carried away by the flowing blood could actually reduce the thermal relaxation of vessels which is calculated based on conductive heat diffusion only. The combination of longer pulse duration and smaller beam diameter could be more susceptible to blood flow effects than lasers with a combination of larger beam diameter and shorter pulse duration.

The 3 ms GentleYAG system meets the pulse duration requirements of selective photothermolysis. Laser energy will be deposited efficiently within the blood vessel maximizing the energy absorption and consequent vessel heating.

Epidermal Cooling

Critical with any laser procedure is how the skin is protected from the laser energy. The cryogen-based Dynamic Cooling Device™ (DCD™) of the GentleYAG is unique in its ability to protect the epidermis during laser therapies. Because the same amount of cryogen is sprayed onto the patient's skin prior to each and every laser pulse, the consistency and reproducibility of this cooling method adds to the speed and convenience of the laser treatment, specially when shorter pulse durations are used.

Other Nd:YAG laser systems rely on contact or air-cooling; their lack of specificity and dependence on operator technique can compromise treatment efficacy—either under-cooling or over-cooling the treatment area.

Summary

Nd:YAG laser systems are increasingly being used to treat leg telangiectasia and reticular veins. Theoretical analysis suggests that Nd:YAG efficacy, in treating these conditions, depends on—selective absorption, optical penetration depth, energy deposition, damage confinement, and the type of epidermal cooling employed—and is significantly improved upon when larger spots for deeper energy penetration are utilized.

Candela's GentleYAG 1064 nm wavelength laser, with its large 12 mm spot size, 3-ms pulse duration, effective fluence range, and DCD, is uniquely capable of treating larger and deeper vessels.

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