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Dermatol Clin 23 (2005) 745 – 755

DERMATOLOGIC
CLINICS

Current Therapy

# Laser Treatment of Vascular Lesions

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Lasers and other light sources have been developed that remove or improve many vascular lesions that were previously untreatable. Port-wine stains are the most notable example. Many port-wine stains are unresectable, but now can be removed in their entirety noninvasively via laser therapy. Vascular lasers and light sources represent a major advance in dermatology for cosmetic and noncosmetic applications. This article reviews the common vascular conditions amenable to laser therapy and the approaches and devices used.

## Guiding principles in laser therapy

The theory of selective photothermolysis was developed by Anderson and Parish [1]. In simple terms, it postulates that a laser can work by heating to the point of destruction a specific targeted structure within the skin. The targeted structure is destroyed without destroying surrounding tissue because the wavelength of laser light used is absorbed preferentially by the targeted structure and not by surrounding tissue. In the case of vascular lesions, the targeted structure is hemoglobin within blood vessels. The hemoglobin is heated, which also heats and destroys the endothelial cells of the blood vessel walls. In an ideal treatment, the vessel is damaged to the point that blood no longer can course through it. Hemoglobin has three wavelengths of light at which it absorbs a maximal amount of energy: 418 nm, 542 nm, and 577 nm. Vascular lasers have been developed to use these absorption peaks to heat and destroy blood vessels selectively.

A second important principle in laser therapy is that of thermal relaxation time. Simply stated, thermal relaxation time is a measurement of the amount of time it takes for a structure to be heated to the point that heat escapes from it to adjacent structures. The larger the structure, the longer the thermal relaxation time because it takes longer to heat a larger object. In laser therapy, the goal is to heat the target structure maximally, but to stop energy input before the heat begins to escape and damage adjacent structures.

The next important concept is that of pulse duration and the need to match pulse duration to the thermal relaxation time of the target. The pulse duration is the amount of time over which a given dose of light is administered to the skin. For example, q-switched lasers have short pulse durations in the nanosecond range. If 5 Joules of light energy is administered with a q-switched laser, that 5-J dose is given very rapidly over nanoseconds. In contrast, vascular lasers have much longer pulse durations in the millisecond range. With a vascular laser, the same 5-J dose of light may be administered over 1 ms, 40 ms, or 1000 ms; much more slowly than with a q-switched laser.

For a given structure in the skin, the amount of energy absorbed and the subsequent heating and destruction that occur vary greatly between the two previous scenarios. In the first example, when the light dose is given quickly (nanoseconds), only very small structures (with subsequently short thermal relaxation times) are heated significantly. The larger structures did not have a chance to heat up because the energy was given so rapidly. Q-switched nanosecond lasers are used to heat and destroy small structures within the skin, such as particles of tattoo pigment or melanin. Conversely, lasers with longer pulse durations administer a given dose of light relatively slowly.

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0733-8635/05/$ – see front matter 
doi:10.1016/j.det.2005.05.023

They heat and destroy larger structures with longer thermal relaxation times. Blood vessels, which are much larger than particles of tattoo pigment, are heated and destroyed by lasers with pulse durations in the millisecond range (termed "long-pulsed lasers"). It follows that larger vessels require longer pulse durations than small vessels for maximal destruction and clinical improvement; this is generally borne out in clinical practice, although multiple other factors come into play as discussed below.

Mismatch of pulse duration and thermal relaxation time can result in adverse effects. Using a pulse duration that is too short (brief) for the targeted structure leads to underheating of that structure and poor efficacy. It also may lead to destruction of smaller unintended targets with shorter thermal relaxation times. Use of pulse durations that are too long can lead to overheating of the target structure. Heat may escape into adjacent structures causing damage.

Finally, another important principle is that longer wavelengths of light penetrate more deeply into the skin. Deeper lesions require a longer wavelength for efficacy. Conversely, more superficial lesions respond to shorter wavelengths.

Two other important terms in laser therapy are "fluence" and "spot size." The fluence is the energy delivered to a given area of skin. It is measured in units of J/cm$^2$. An increase in fluence is an increase in energy emitted by the laser. Increasing the fluence can increase efficacy, but also can increase the risk of scarring if safe parameters are not observed. Spot size is the size of the laser beam administered to the skin surface. In most cases, it is circular, although rectangular spot sizes also are available. Use of a 5-mm spot size means that a circular beam of light measuring 5 mm in diameter is administered to the skin. In general, moving to a larger spot size requires a decrease in energy (a lower fluence) and vice versa. Larger spot sizes also tend to have more scatter (and slightly less efficacy) at the periphery. This difference is usually not noticeable clinically, especially with spot sizes 10 mm and smaller.

In practice, the interaction between laser light and tissue is complicated. Perfectly selective photothermolysis is not yet possible. Multiple structures within the skin absorb laser light to various degrees. If too much energy is absorbed by nontarget structures, blistering, scarring, and dyspigmentation can result. Absorption by epidermal melanin is particularly problematic, especially in patients with Fitzpatrick skin types IV through VI. In these patients, pigmentary alterations (hyperpigmentation and hypopigmentation) resulting from damage to melanocytes are common. Epidermal melanin absorption also can lead to blistering and to injury of nearby dermal structures, resulting in scar formation. Absorption of light by melanin decreases with longer wavelengths. In the case of vascular lasers, longer wavelength lasers still have a high incidence of melanin-related adverse effects (see treatment tip #3 later).

In addition to the direct effects of laser energy on the skin, there are secondary effects of laser injury, such as the inflammatory response. Inflammation and the subsequent changes it produces may play a large role in the ultimate clinical improvement seen with laser therapy. This inflammatory response may help to explain why vascular lesions usually do not disappear immediately with laser treatments, but rather fade gradually in the days and weeks after treatment.

## Brief history of vascular laser development

Port-wine stains were the initial vascular lesions extensively studied in laser therapy. Argon 488-nm and 514-nm and continuous wave dye 577-nm and 585-nm lasers were used initially. They were associated with a relatively high risk of scarring and pigmentary change [2,3]. Ablative lasers, such as the 10,600-nm carbon dioxide and 2940-nm erbium: yttrium aluminum garnet (Er:YAG) lasers, also were used [4]. These did not target the vasculature, but rather obliterated the lesion as the laser energy was absorbed primarily by water ubiquitous in the skin. Because destruction of a portion of the dermis was necessary for lesion removal, some form of scarring was the norm. Copper vapor 510-nm and 578-nm lasers represented an improvement over the previous lasers above [5]. However, the pulsed dye laser (PDL) largely replaced other lasers in the treatment of port-wine stains.

The PDL with wavelengths ranging from 585 to 600 nm was perfected by Anderson and his group in the 1980s [1,6]. It has become the treatment of choice for port-wine stains. Subsequently the KTP 532-nm laser was found to be useful in the treatment of fine telangiectasias, and intense pulsed light (IPL) systems are effective for diffuse facial erythema. The newer long-pulsed 532-nm KTPs, PDLs, 755-nm alexandrite, diode (with wavelengths 800–900 nm), and 1064-nm neodynium:yttrium aluminum garnet (Nd:YAG) lasers may be helpful in the treatment of leg varicosities and other vascular lesions. Currently a wide array of lasers and light sources are available to the clinician for treatment of vascular lesions, and new devices are being developed constantly.

Many different types of vascular lesions have been shown to resolve or substantially improve with laser therapy, including port-wine stains, hemangiomas,