REVIEW ARTICLE

Past, present, and future: Vascular lasers/light devices

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Abstract

Vascular lasers were among the first available cutaneous light-based technologies. The past 20 years has seen a variety of safe and effective laser and light-based vascular treatment devices. This article provides a review of the medical and scientific literature, which concludes that newer lasers have led to increasing success and safety in the treatment of cutaneous vascular lesions.

Key words: Vascular lesions, laser, intense pulsed light

Introduction

Oxyhemoglobin (HbO$_2$), the targeted chromophore in vascular lesions, has a multi-peak absorption spectrum in the visible range of the electromagnetic spectrum: 410–429 nanometers (nm), 541 nm, and 577 nm. In addition to these peak absorptions in the yellow and green visible light spectrum, HbO$_2$ also has a broad but less significant absorption peak in the red and near-infrared range between 700 nm and 1000 nm (Figure 1).

Utilizing the principle of selective photothermolysis (SPTL), postulated by Anderson and Parrish, lasers at the shorter visible wavelengths should theoretically produce the greatest results. However, a second chromophore, melanin, allows for concomitant competing absorption at these shorter wavelengths. This dual absorption does not permit selectivity. Unwanted possible side effects including hypopigmentation result. This interference necessitates the need to expand the range of wavelengths used to treat vascular lesions.

Past

The original continuous wave 488 nm and 514 nm argon laser (AL) emits a blue-green light. Later, quasi-continuous wave systems were developed that emitted a yellow light, including the 578 nm copper vapor/bromide laser (CVL). Elemental copper was heated to produce this visible light delivered in a train of short 20 nanosecond (ns) pulses with rapid repetition. The advantage with these yellow light systems was a higher degree of absorption by HbO$_2$ and a lower degree by the competitive epidermal melanin (Figures 2 and 3). These shorter wavelength lasers match the first and second absorption peaks for HbO$_2$. Despite these desirable absorption characteristics, both the continuous wave AL and the advanced mechanical shuttering CVL fail to meet today’s requirements for selective photothermolysis. Non-specific thermal damage of tissue surrounding the targeted vessel led to scarring. Such scarring ranged from just-visible textural changes to hypertrophy and pigmentary changes.

Subsequent laser systems utilizing gas as an active medium, such as the krypton 568 nm laser, also shared the same disadvantages: concomitant melanin absorption and lack of adequate penetration depth.

Present

In 1989, the flashlamp-pumped pulsed dye laser (PDL) was the first laser developed on the principles of SPTL. This laser revolutionized the treatment of vascular lesions. A flashlamp was used to energize a fluorescent liquid dye (rhodamine) which subsequently generated a pulse of yellow light. The 585–595 nm PDL was introduced for the treatment of
superficial port wine stains (PWS) and its benefits in the treatment of superficial congenital hemangiomas has also been noted.

Still deeper penetrating, near-infrared lasers have been used to target the deeper vessels in subcutaneous and combined PWS. Particularly useful for the deep, hypertrophic PWS and PDL-resistant malformations are the 755 nm alexandrite or 1064 nm Nd:YAG (neodymium:yttrium-aluminum-garnet) lasers delivered at high fluences, typically 50–250 J/cm$^2$. Such lasers are ideally used in combination with adequate skin cooling (1).

Traditional 585 nm or 595 nm PDL treatment is also ideal for focal lesions, such as facial telangiectasias. Parameters used include fluences between 8 and 10 J/cm$^2$, a 5 or 7 mm spot size, and pulse durations in the millisecond range. Immediately following the procedure, purpura generally develops. Such purpura may require 7–10 days of downtime depending on the treated cosmetic area.

The efficacy of PDL in the treatment of vascular lesions is undeniable. More recently, longer wavelengths (595 and 600 nm), larger spot sizes (10–12 mm), higher peak fluence potential, and longer pulse durations (1.5–40 ms) allow for better treatment of deeper vascular lesions (2). Versatile qualities of this laser, and the advent of dynamic cooling devices, make this laser superior to earlier quasi- and continuous wave lasers (Figures 4–7).

A versatile alternative for superficial cutaneous vascular lesions is the potassium-titanyl phosphate (KTP) long-pulsed frequency-doubled Nd:YAG laser. At a wavelength of 532 nm, this laser emits green light and produces long pulse durations ranging from 1 to 100 ms. These longer pulse durations gradually heat the blood vessel, without blood vessel wall rupture and subsequent purpura (Figures 8 and 9). Clark et al. varied pulse duration and fluence depending on the width of the vessel. Smaller vessels (<1 mm) responded to a pulse.

Figure 1. …Hemoglobin absorption curve…

Figure 2. Before treatment with the copper vapor laser.

Figure 3. After treatment with the copper vapor laser.

Figure 4. Before treatment with the pulsed dye laser.

Figure 5. After treatment with the pulsed dye laser.
duration of 10 ms and a fluence of 10–12 J/cm²; mid-range vessels (1–2 mm) to 12 ms and the same fluence range; larger vessels (>2 mm) to a longer pulse width of 12–14 ms and a higher fluence of 12–14 J/cm² (3).

Side effects frequently seen with the KTP are edema and crusting; atrophic scars have also been well documented, particularly using smaller spot sizes to treat nasal telangiectasias. Because of the shorter wavelength there is greater absorption by epidermal melanin in darker skin types, whether ethnic or sun-induced, and this limits the laser’s use with Fitzpatrick skin types I–III.

Red and near-infrared lasers take advantage of this lesser, albeit significant absorption range of oxyhemoglobin and reduced hemoglobin (700–1200 nm). The advantage is deeper penetration and a lower absorption coefficient of melanin. Treatment of hypertrophic PWS with a 755 nm alexandrite laser, using a 3 mm spot size and fluences ranging from 30 to 85 J/cm² with dynamic cooling have been demonstrated by No et al (4). These authors use this same laser at different settings for therapy of deeper hemangiomas. Other studies also support the use of various longer wavelength, longer pulsed lasers (810, 940, 980 nm) and dynamic cooling in the treatment of larger and deeper vascular lesions.

The 1064 nm Nd:YAG can penetrate up to several millimeters into skin and therefore has been successfully used to treat a variety of deeper, more resistant congenital and acquired vascular lesions. Previous studies demonstrated the efficacy of treatment of voluminous vascular congenital tumors, such as subcutaneous and mixed hemangiomas, and a variety of venous malformations (5). Moderate to significant improvement of smaller red and red-blue facial telangiectasias using the Nd:YAG laser with a 3 mm spot size, 120–170 J/cm² and 5–40 ms pulse durations with contact cooling has also been reported (6).

The 1064 nm Nd:YAG laser has been successfully used to treat lower extremity telangiectasias and feeding reticular veins up to 4 mm in diameter (Figures 10 and 11). Earlier reports claim this longer wavelength has poor hemoglobin absorption and requires high fluences between 150 and 300 J/cm². More recent studies have shown that effective treatment of vessels is dependent on pulse width (PW); larger vessels have longer thermal relaxation
times (TRT) and thus require a longer PW for effective obliteration. A longer PW is required to selectively close larger, deeper targeted vessels while sparing the more superficial smaller vessels (7). Sadick (8) used a Nd:YAG laser with a spot size of 6 mm and reported successful parameters for various vessel widths: 0.2–2.0 mm vessels responded to a double pulse of 7 ms at 120 J/cm$^2$ and vessels of 2.0–4.0 mm in diameter responded to a single pulse of 14 ms at a fluence of 130 J/cm$^2$. Omura et al. (9) reported a high clearance of reticular leg veins using 50 ms PW and a fluence of 100 J/cm$^2$ with contact cooling.

Visible/near-infrared broad spectrum intense pulsed light (IPL) devices emit non-coherent light in the 500–1200 nm range capable of targeting vessels. Cut-off filters are available to produce green and yellow light to more specifically target HbO$_2$ at various depths. A range of millisecond pulse durations of light can be delivered as single, double, or triple pulses. IPL devices offer a wide variety of parameters to achieve a peak target absorption of heat.

The expected IPL clinical end-point is vessel disappearance or minimal graying, followed by mild erythema. Short-lived erythema is noted after use of this device when treating facial telangiectasias, PWS, and small diameter leg veins.

IPL systems are ideal for the treatment of telangiectasias, the ‘ruddiness’ associated with rosacea, and photodamage in individuals with Fitzpatrick skin types I–III.

**Future**

A combination of different wavelengths may yield a better clinical outcome for more difficult to treat vascular lesions such as resistant PWS, other congenital vascular malformations, acquired vascular lesions, and some leg veins. With the development of a dual wavelength laser system producing near simultaneous 595 nm yellow light and a 1064 nm near-infrared light, more difficult to treat vascular lesions may be more easily targeted (10). The PDL is used initially to emit a coherent light at 595 nm. This 595 nm wavelength lies within the second peak of the oxygenated hemoglobin absorption curve. Subsequently, the Nd:YAG laser is used on the same lesion and takes advantage of the third, although lesser but still significant, broader absorption peak of hemoglobin. In addition, PDL-induced methemoglobin formation becomes an even better
chromophore for subsequent Nd:YAG laser irradiation (Figure 12).

**Conclusion**

Vascular lasers and light sources offer a minimally invasive therapeutic option for the treatment of a wide array of congenital and acquired vascular lesions. In the last 20, such technology has dramatically changed the approach to the treatment of cutaneous vascular lesions.

**References**