Update on Lasers and Light Devices for the Treatment of Vascular Lesions

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Patients frequently present to dermatologists for the treatment of vascular lesions, including facial telangiectases, diffuse redness, port wine stains (PWS), hemangiomas, and leg veins. There are many laser and light devices that can be used with excellent results. This article summarizes the available platforms that are commonly used for the treatment of superficial vascular lesions. Newer devices and techniques are highlighted with respect to the unique characteristics of individual lesions.
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The principle of selective photothermolysis, originally described by Anderson and Parrish,[1] defined how laser energy was absorbed by a particular chromophore within the skin leading to a specific biologic effect while sparing collateral structures. In this fashion, laser and light devices have become refined during the past several decades, leading to our current ability to apply high fluences to tissues very specifically resulting in selective destruction of unwanted lesions while sparing the patient from nonspecific side effects such as crusting, bleeding, scabbing, or scarring.

The range of superficial vascular lesions that can be treated with laser and light devices continues to expand. Each lesion has unique qualities (ie, location depth, vessel caliber) that result in particular device selection and treatment concerns. Regardless of lesion, the chromophore remains oxyhemoglobin, which has absorption over a broad range of wavelengths with peaks at 418, 542, and 577 nm. Figure 1 shows the different absorption spectra of the various chromophores found in the skin. The most commonly used devices used today include the 532-nm potassium titanyl phosphate (KTP), the 595-nm pulsed dye laser (PDL), the 755-nm alexandrite, the 1064-nm neodymium-yttrium-aluminum-garnet (Nd:YAG), and various intense pulsed light (IPL) systems.

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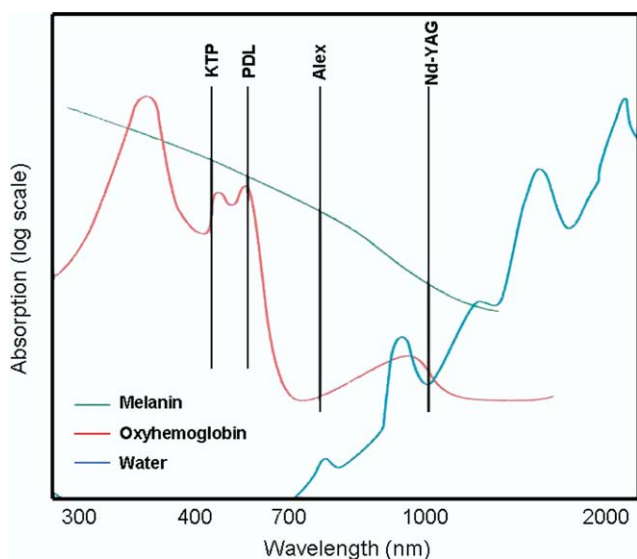
Lasers and Light Devices With Vascular Applications

KTP Laser

The KTP laser is a Nd:YAG laser that is frequency-doubled and emits green light at 532 nm. Superficial vessels can be treated by taking advantage of the close proximity of the absorption peak of oxyhemoglobin at 542 nm.[2] With commonly available devices, spot sizes can range from 1 mm to 10 mm, with variable pulse widths (1-100 ms). Contact cooling is used with chilled sapphire windows with conduction gel during treatments. Epidermal melanin can also be targeted with the KTP laser, making it a reasonable choice for photorejuvenation encompassing both vascular and pigmented lesions.[3] High fluence treatments with small spot sizes have, however, been known to induce atrophic scars. In addition, the relatively shallow depth of penetration of this wavelength would theoretically make it limited to the treatment of superficial lesions on the face neck and chest, although there have been reports of KTP lasers being used with ultra long pulse durations (50 ms) to treat lower leg telangiectases.[4]

Pulsed Dye Laser

Modern PDL systems emit wavelengths of 585 or 595 nm and are widely considered to be the treatment of choice for hemangiomas, PWS, facial telangiectases, and rosacea.[5] The longer wavelengths used by today's PDLs were engineered to allow for deeper tissue penetration in the treatment PWS.[6,7] In previous generation platforms, multiple passes and/or pulse stacking are often necessary to avoid purpura.[8,9] A new generation PDL has been introduced (Perfecta, Candela Corporation) that uses a novel pulse structure where each macropulse is subdivided into 8 micropulses. With the goal of

Figure 1 Oxyhemoglobin absorption curve. In: Dermatology (Bolognia JL, Jorizzo J, Rapini R, eds). Modified with permission by Elsevier Limited; London, Copyright 2003.

single-pass treatments, greater total fluences can be delivered to tissues in a gentle fashion with evenly spaced micropulses that mitigate the risk of purpura.[10]

Despite good absorption by melanin of the 595-nm wavelength, the efficiency of the commonly used dynamic cooling devices usually inhibit epidermal heating and pigment photothermolysis. The newest advance of the 595-nm PDL is its capability to target pigmented lesions. The aforementioned novel PDL uses a "compression handpiece" that allows the operator to selectively blanch out any associated vascular lesion and take advantage of the 595-nm wavelength with pulse-widths effective for melanin. Without transient compression, the pulse widths that exceed the thermal relaxation time of melanosomes would result in undesired purpura by pulsing coexistent vascular structures. Without cryogen spray fired in conjunction with a laser pulse, as is done with the compression handpiece, epidermal melanin can be sufficiently heated, leading to improvement of dyschromias. Several recent studies have investigated these advances of pulse structure and the compression handpiece in the treatment of both vascular and pigmented lesions.[11-13] In this author's experience, the PDL with compression handpiece was able to clear >90% of small (<0.6 mm) telangiectases and dark lentigines after three 2-pass treatments each spaced between 3 and 4 weeks apart.[12] With the compression handpiece, individual lesions were targeted with fluences between 6.5 and 8 J/cm² with a 1.5-ms pulse duration. After the first pass, an additional pass with cryogen spray cooling was then performed targeting vascular lesions with fluences between 9.5 and 10 J/cm² with a 20-ms pulse width. Figure 2 shows a typical patient after 3 treatments with the compression handpiece followed by another pass with the standard handpiece. The learning curve, however, is steep with the compression handpiece, and purpura can easily result after poor compression technique, especially over facial areas with less underlying bony structure (eg, central cheeks). Absolute visual con-

Figure 2 A typical patient before and after 3 treatments with a novel PDL: One pass with the compression handpiece (10-mm spot size at 6.5-8 J/cm², 1.5-ms pulse width followed by another pass with the standard handpiece (10-mm spot size at 9.5-10 J/cm², 20-ms pulse width, with cryogen spray cooling).

formation of telangiectatic blanching leads to predictable, purpura-free treatments. Furthermore, and in keeping with the goal of purpura-free treatments, one should treat the pigmented lesions first. This ensures that there is minimal to no background erythema and an increased pigment:vascular ratio within the compression handpiece treatment zone.

Another recent advance of the PDL is the availability of a 3- × 10-mm spot. This allows higher overall fluences to be delivered to specific vessels and has been reported to be effective for the treatment of spider veins of the lower extremity. Bernstein treated patients with Fitzpatrick skin types I-III multiple times using an average fluence of 20.4J/cm² and a pulse duration of 40-ms with the 3- × 10-mm spot. Marked improvement was noted without any textural change at the treatment site upon blinded physician review.[14]

Alexandrite Laser

The 755-nm wavelength alexandrite laser is positioned between the 532- to 595-nm and 1064-nm lasers. At 755 nm, there is twice the photon absorption by hemoglobin than in 1064-nm lasers. Compared with 532- to 595-nm lasers, there is less hemoglobin absorption, but much deeper photon penetration and scattering. Compared with 1064 nm, there is more effective vessel heating per J/cm². Most studies of alexandrite lasers have focused on the treatment of leg veins with varying degrees of success. Vessels >1.0 mm or those smaller than 0.3 mm respond poorer than medium sized vessels likely due to inadequate heat generation in larger vessels or by the infrared wavelengths inherently bypassing the smaller vessels.[15,16]

Nd:YAG Lasers

Nd:YAG lasers can penetrate deeply (4-6 mm)[17,18] and have been used for years for the treatment of PWS and leg veins. With the deeper penetration, pain becomes a factor during treatments and anesthesia is usually required. One benefit of the 1064-nm wavelength is it's inherently lower absorption coefficient for melanin. With this wavelength there is less concern for coincident epidermal damage and it can be used more safely in pigmented patients.[5] Nevertheless, epidermal pigment must be protected in darkly pigmented individuals with some sort of cooling. Options common to 1064-nm devices include cryogen spray cooling (Dynamic Cooling Device, Candela Corporation), forced cold air, or contact cooling via chilled sapphire windows or conductive metal plates.

IPL Systems

IPL systems emit polychromatic light in a broad wavelength spectrum. Attached to these devices are filters designed to allow a defined wavelength band to penetrate the skin and target specific structures.[19] Depending on the attached filter, which result in the application of wavelength bands in the range of 500 to 1400 nm, superficial or deeper vessels may be treated. Many different vascular lesions have been treated with IPL, including PWS, hemangiomas, diffuse facial telangiectases, and poikiloderma of Civatte. Depending of the cutoff filter used, pigmented lesions and hair can also be treated

with IPL devices, adding to their versatility. Regarding vascular lesions specifically, most modern IPL devices are used to treat facial telangiectases and, by and large, treatments are extremely tolerable with predictable results that are comparable with many laser platforms. Disadvantages of IPL devices are their usually bulky handpieces and large spot sizes, making maneuverability in small concave areas of the face difficult. Another disadvantage is the lack of real-time visibility of the treatment area due to the need of contact cooling for epidermal protection.

Vascular Lesions

Facial Telangiectases

Telangiectases are extremely commonplace in today's adult population, occurring in at least 15% to 20% of the population. These are small dilated vessels with diameters between 0.1 and 1.0 mm. Many cutaneous disorders are associated with an increase in telangiectases, most commonly acne rosacea. Telangiectases can also be found in association with other processes such as photodamage, overuse of topical steroids, hyperestrogenemic states, liver disease, radiodermatitis, connective tissue diseases, and various vascular genodermatoses. It is commonplace to find telangiectases in association with surgical scars. Treatment of facial telangiectases is one of the most commonly performed procedures by laser surgeons. The most commonly used devices used to treat telangiectases include the 532-nm and 595-nm lasers and IPL devices with cutoff filters between 500 and 1400 nm. Typical result from treatment with the PDL can be seen in Fig. 3.

Traditionally, vascular lesions have been treated with PDL at purpuric pulse durations with excellent results despite the 7 to 10 days of bruising. To prevent bruising, previous work had shown that multiple passes and/or pulse stacking could lead to improved vessel clearance, but such techniques were time consuming and led to longer, uncomfortable treatment sessions.[8,9] Subpurpuric fluence settings with a 10-mm spot size range from 6.5 J/cm² to 7.5 J/cm² with a pulse duration of

Figure 3 A typical patient before and after 3 treatments with a PDL (10-mm spot size, 9.0-10 J/cm², 10-20-ms pulse width with cryogen spray cooling).

6 to 10 milliseconds.[8,9] Consumer pressure has driven industry to create devices that can lead to excellent clearance of vascular lesions within the context of nonpurpuric "zero-downtime" treatments. As mentioned previously, a novel PDL with an advanced micropulse structure is now available. Single-pass treatment of telangiectases is now possible with a purpura threshold (with a 10-mm spot) of over 10 J/cm^2 with a macropulse duration as short as 10 ms.[10] In the context of overall photorejuvenation encompassing treatment for vascular and pigmented lesions a recent comparative, multiple treatment, split-faced study found the novel PDL with a compression handpiece to be comparable to high fluence IPL. In this study, vascular lesions improved to a greater degree than IPL, but treatments took longer, were more painful and resulted in more posttreatment edema.[20]

A recent comparative study noted the KTP laser (Gemini; Laserscope, San Jose, CA) to be superior to an older PDL (V-Beam; Candela Corporation, Wayland, MA) for facial redness and discrete facial telangiectases.[22] Another split-faced study noted it to be comparable with IPL (Starlux, Palomar Medical Technologies, Burlington, MA) in achieving improvement in vascular and pigmented lesions (one session), but that it was more painful and caused more edema.[23]

IPL has been widely used in the treatment of facial telangiectases. The filters used for vascular lesions frequently encompass wavelengths that are readily absorbed by melanin. Careful attention to detail is necessary with the newer high-powered devices, especially when treating darker patients. Distinct "postage-stamp" marks corresponding to the treatment spots are commonly seen in tanned or darker patients that have been treated with overly aggressive settings. Test spots are strongly encouraged with these platforms with attention to tissue response. This takes a trained, experienced laser surgeon to note and adjust settings accordingly (eg, using longer pulse durations). The frequency of such adverse events highlights the danger of having "technicians" operate these devices at high fluences.

Hemangioma

Hemangiomas are the most common benign tumors of childhood.[21] These are tumors and not malformations or hamartomas, such as a PWS, in that they are characterized by an initial phase of proliferation that is variably followed by a period of slow involution. They are positive for GLUT-1, a glucose transporter that is highly expressed in placental tissue. They are 10 times more common in children of women undergoing chorionic-villus sampling during pregnancy.[22] Complete regression is usually observed in time. Nevertheless, depending on their size, clinical behavior (eg, growth, ulceration, scarring), and location (eg, periocular, laryngeal distribution), they may have devastating consequences. Lasers are commonly used to treat hemangiomas for 3 distinct indications: treatment of the proliferative phase, treatment of ulcerations, and the treatment of residual telangiectases after involution is complete.[21] Various devices can be used to treat hemangiomas, including the PDL, Nd:YAG, alexandrite, and

KTP-based platforms. Results seen after multiple PDL treatments are shown in Fig. 4.

Without question, the most commonly used device is the PDL which is generally regarded as the treatment of choice for superficial lesions. It does not penetrate as deep as the longer-wavelength based platforms but has special utility in the treatment of photocoagulating ulcerated lesions leading to improved reepithelization and decreasing pain.[23]

Thicker, deep lesions may have an increased deoxyhemoglobin:oxyhemoglobin ratio, thereby shifting the absorption curve of these lesions to the near-IR range (700-1200 nm). The more deeply penetrating 1064-nm and 755-nm lasers are less commonly used in the treatment of deeper hemangiomas and should probably only be performed by experienced laser surgeons because of the increased risk of deep thermal injury and the subsequent scarring that can result. Oxyhemoglobin strongly absorbs 532 nm, but when applied transcutaneously, its relative poor penetration makes it a poor option when treating hemangiomas. The 532-nm platform has been shown to be inferior to the PDL in treating hemangiomas.[24] Although uncommonly used, intralesional bare fiber KTP treatment of hemangiomas has been reported as an option when treating the deeper components of cutaneous hemangiomas.[25]

Port Wine Stain

Port wine stains (PWS), in contrast to hemangiomas, are localized defects of vascular morphogenesis, probably caused by disruptions in pathways monitoring embryogenesis and vasculogenesis.[26] Most if not all PWS are congenital; however, there are reports of antecedent trauma playing a role.[27] Composed of ectatic capillary malformation in the upper layers of the dermis, PWS are also associated with some genodermatoses such as Sturge-Weber and Klippel-Trenaunay syndromes. PWS usually grow in proportion to the child and may thicken with age. In addition, associated structures such as the lips, gingivae and tongue may enlarge leading to topographic dysmorphism.

The PDL is the most commonly used platform in the treatment of PWS. Commonly used fluences used in treating PWS are 4 to 12 J/cm^2 with pulse widths of 1.5 to 10 ms with a 7-mm spot size. Newer devices have larger spots and, in the future, may prove to be more effective because of their increased depth of penetration. Larger spot sizes generally require a reduction in fluences; however, with new micropulse advances, there very well may be less reduction than expected to attain the desired clinical outcomes of deep purpura without significant graying. Multiple treatments are the rule and it is generally accepted to treat the superficial vessels first before targeting the deep, more recalcitrant ones.[28] The results of multiple treatments with the PDL can be seen in Fig. 5. However, not all PWS will clear with PDL treatment. Most studies show that less than 20% of PWS can be completely lightened, although 70% will lighten by 50% or more whereas 20% to 30% respond poorly.[29,30] As eloquently summarized in a recent review by Zaid and Handley,[29] certain PWS may respond poorly as the result of multiple factors,
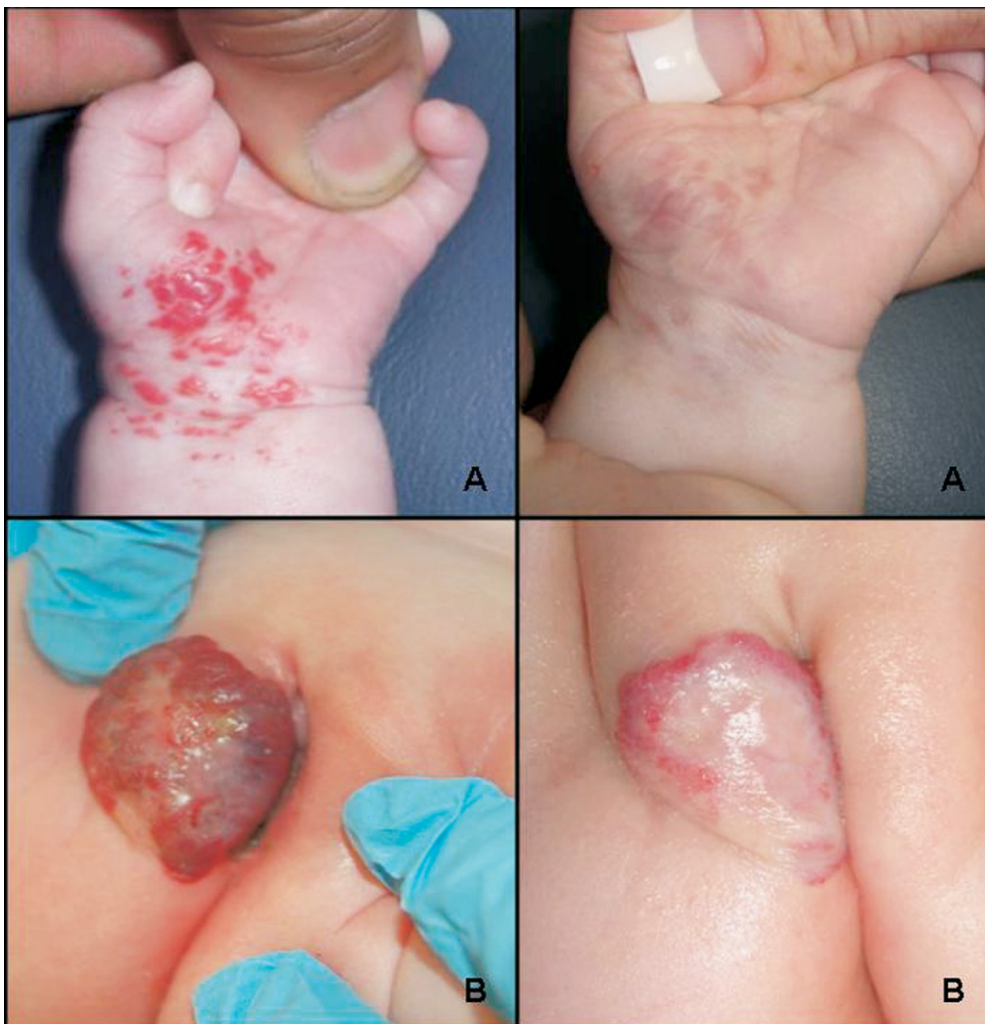
Figure 4 A superficial hemangioma of infancy (A) and an ulcerated nodular hemangioma of infancy (B) before and after multiple treatments with a PDL: Lesion B was also received multiple intralesional corticosteroid injections. Courtesy of S. F. Friedlander, MD, PhD.

including: (1) inadequate depth of penetration, (2) inadequate conduction of laser-induced heating from centrally situated hemoglobin to vessel walls, (3) inadequate blood volume (ie, not enough chromophore to absorb/transmit heat) to destroy smaller vessels, and (4) inadequate fluence entering deeper capillaries due to obstructive fibrosis that was caused by previous treatment of superficial vessels. The last point mentioned argues against the commonly held dictum of treating the superficial vessels first.[28]

Treatment earlier in life may lead to fewer treatments and may improve outcome.[31,32] A recent study has suggested that frequent, high energy pulsed-dye laser treatments are safe and highly effective in improving facial PWS in infants ≤6 months of age and that they should be referred for PDL treatment during early infancy.[33]

Less commonly used modalities used to treat PWS include IPL, KTP, and Nd:YAG-based platforms.[34-36] However, when used solely, all have generally poorer side-effect profiles than the PDL due to high melanin absorption (IPL, KTP) or increased depth of penetration with a inherent risk of scarring

(Nd:YAG). New technologies, such as sequential varying wavelengths have been applied with promising results.[37,38] With such devices such as the Cynergy Multiplex (Cyanosure Inc, Westford, MA), a 595-nm pulse is delivered and followed by 1064-nm pulse. In this way, methemoglobin is formed in the vessel from the initial pulse which has a significant absorption peak near 1064-nm, thereby increasing the absorption of laser energy leading to effective treatment of typically recalcitrant lesions.

Poikiloderma of Civatte

Poikiloderma of Civatte is a ruddy sun-induced dyspigmentation disorder with a prominent vascular component. The typical tetrad of features include hyper- and hypopigmentation, telangiectases and atrophy. It presents in the fifth to sixth decades of life and is histologically characterized by solar elastosis, dilated superficial papillary vessels with an atrophic epidermis featuring irregular epidermal melanin distribution.[39] Many lasers, including the KTP, PDL, and IPL,

Figure 5 A patient's PWS before and after 4 purpuric treatments with a PDL (7-mm spot size, 8-9 J/cm^2, 1.5-ms pulse width, with cryogen spray cooling). Courtesy of E.V. Ross, MD.

have been reported as effective owing to the lesion's rich vascular and melanin based chromophores.[40-42] Great care and conservative settings are required when treating this condition, as is the case in treating any chronically bronzed skin with lasers as severe depigmentation has been reported.[43] Most recently, there has been report of using a 1550-nm fractional device (Fraxel SR Laser, Reliant Technologies Inc, Mountainview, CA) at a pulse energy of 8 mJ with a final density of 2000 MTZ/cm^2. These settings lead to approximately 18% of the treated area being photothermolysed. This device uses water as its chromophore and nonspecifically targets the dermal vasculature and possibly targets the water component of blood within the vessels.[44]

Leg Veins

Vein therapy is an extremely common request in any cosmetic practice. Visible or "spider" veins on the leg affect approximately 80% of women in the United States.[45] Age, hormonal factors, and genetics all play a role in the development of visible leg veins. The venous network within the lower extremities is complex and involves superficial and deep plexi. The superficial plexus is found within the skin, superficial fascia, and in the subcutaneous tissue plane. Perforating veins connect this superficial plexus to the deep venous system within the underlying muscle. The smallest, bright red vessels are commonly called telangiectases (up to 0.3 mm in diameter). Venulectases are slightly larger (0.4-2 mm) vessels that may be red or blue in color.[46] These drain into the reticular vessels (4-6 mm) that are named for their location in the reticular dermis and subcutaneous fat.[47] Variations in vessel

size, depth, and oxygenation greatly influence the modality and efficacy of leg vein therapy.[3] Although sclerotherapy is still widely considered to be the gold standard, there are times that laser therapy is a reasonable alternative and is almost always a useful adjunct. Lasers can be extremely useful in treating vessels that cannot be cannulated, those presenting as left over telangiectatic matting from sclerotherapy, or in such areas that are prone to ulceration such as the ankle. The Nd:YAG, PDL, KTP, alexandrite, and IPL platforms have all been used successfully to treat leg veins. Typical results of using a Nd:YAG laser for leg veins can be seen in Fig. 6.

The Nd:YAG is a popular choice in treating leg veins. Its longer wavelength can penetrate deeper to target veins up to 3 mm in diameter. A single-treatment study evaluated patients with 1- to 3-mm reticular veins who received one treatment with a 1064-nm Nd:YAG laser (Coolglide, Altus, Burlingame, CA) at fluences of 100 J/cm^2 with a 50-ms pulse duration and found that two-thirds of vessels cleared more than 75% with just one treatment.[48] Fluence should be chosen to achieve the end point of immediate vessel disappearance (stenosis) or bluing (thrombosis).[46] It has been reported that lower fluences (100-200 J/cm^2) work better for larger vessels (1.5-3 mm) and that higher fluences of 250 to 400 J/cm^2 are require for vessels <0.5 mm.[49] Others have reported that compared with shorter pulses (<20 milliseconds), longer pulses may provide gentler heating of the vessel and a greater ratio of contraction to thrombosis.[50] In 2003, Sadik used an Nd:YAG for the treatment of red and blue telangiectatic vessels from 0.2 to 3.0-mm in diameter. For red vessels a 1.5-mm spot size was used with fluences ranging

Figure 6 A patient's leg veins before and after one treatment with a 1064-nm laser (6-mm spot size, 140 J/cm², 3-ms pulse width, with cryogen spray cooling). Courtesy of E.V. Ross, MD.

from 400 to 600 J/cm² and with pulse durations from 30 to 50 ms. Blue vessels (1-3 mm in diameter) were treated with a 3-mm spot and fluences between 250 to 370 J/cm² with pulse durations between 50 and 60 ms. At 6-month follow-up, 80% of patients had greater than 75% clearing and ninety percent of patients were highly satisfied with their treatment results.[51]

Originally designed for the treatment of PWS, the PDL has an advancing indication in the treatment of smaller lower extremity vessels. The available 3-mm × 10-mm spot has been designed to minimize fluence application to collateral tissue while focusing the beam on small telangiectatic vessels. As mentioned previously, a recent study found 44% of patients experienced marked (>50%) or excellent (>76%) improvement.[14] In separate studies, both Kono and Tanghetti have reported the PDL to be efficacious in treating lower extremity leg veins, but hyperpigmentation was seen in more than half of treated patients in both studies.[52,53]

The KTP laser does not penetrate as deeply as the PDL or the Nd:YAG and is strongly absorbed by melanin. A study by Spendel and coworkers in 2002 treated patients 3 times at 6-week intervals with a 1-mm spot KTP laser with fluences between 15 and 16 J/cm², 10-ms pulse width at 3 pulses-per-second. In patients who had veins <0.6 mm; 33% had complete clearance, 40% had a decrease in vessel size, and 27% had no change. The incidence of hyperpigmentation was 15%, 38% and 50% in patients with Fitzpatrick skin types I, II, and III, respectively.[54]

The near-IR lasers such as the alexandrite (755 nm) laser allow deeper penetration than either the KTP or PDL platforms. A study in 2000 reported 87% of patients experienced greater than 50% improvement in lower-extremity vessels. Lesions were treated with up to 3 passes with the 755-nm laser with an 8-mm spot and fluences between 60 to 80 J/cm² and 3-ms pulse width to the clinical endpoint of vessel disappearance or thrombus formation. As with other platforms, hyperpigmentation was a common side effect persisting in 26% of sites after 12 weeks.[55]

IPL systems emit a broad range of wavelengths depending on attached filters. Smaller vessels seem to respond better to IPL with a reported 90% clearance rate in vessels <0.2 mm in diameter and 80% clearance rate in vessels between 0.2 and 1 mm in diameter. As is common with these devices when operating at high fluences and shorter pulse durations, erythema, burning, purpura and dyspigmentation and scarring can result.[56]

Miscellaneous

There are many lesions that are not traditionally thought of as "vascular" but that have a vascular component making them amenable to treatment with various lasers and light devices. Warts and molluscum contagiosum have been treated effectively with the PDL and the KTP lasers.[57-59] Molluscum contagiosum has also been reported to be a side effect of PDL treatment, presumably due to decreased barrier function or an inoculation phenomenon.[60] In addition, there has been report of the PDL effectively treating a nonhealing Mohs surgery defect that was left to heal secondarily and had developed chronic hypergranulation tissue.[61] Other conditions in which vascular lasers have played a part in treating include keloids, venous lakes, angiokeratoma of Fordyce, reticular erythematous mucinosis, unilateral nevoid telangiectasias, and the telangiectases associated with hereditary hemorrhagic telangiectasias.[62-67]

Conclusions

There are many different laser and light-based platforms that can be used for the treatment of vascular lesions. Each platform has its own unique advantages and disadvantages and, when performed by skilled providers, laser and light therapy generally enjoys a very favorable risk to benefit ratio. The future is bright with many new and improved devices being brought to market and will no doubt lead to our improved ability to safely, effectively and permanently treat vascular lesions.

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