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REVIEW

# Management of vascular lesions using advanced laser technology

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***Abstract*:** One of the most widely used cutaneous applications of Light Amplification by Stimulated Emission of Radiation (laser) concerns the treatment of vascular lesions. During the past two decades, very significant advances in the application of laser technology in dermatology have occurred, with selective photothermolysis being the most important. This review focuses on the application of modern laser devices (Pulsed Dye Laser, or PDL; potassium titanyl phosphate laser, or KTP; diode laser; and neodymium-doped yttrium-aluminium-garnet laser, or Nd:YAG), as well as the combination of laser and photodynamic therapy (PDT) for the treatment of vascular lesions. In lar, both congenital (haemangiomas and port-wine stains) and acquired vascular lesions (facial and leg telangiectasias, rosacea, Poikiloderma of Civatte, spider angioma, pyogenic granuloma, and venous lakes) are discussed. The review of many recent research studies demonstrates that modern applications of lasers in dermatology constitute the finest method for the treatment of vascular lesions, combining the advantages of invasive therapy with the security offered by non-invasive therapy, while in certain cases they are the single and only choice for the treatment of these lesions.

***Keywords*:** Vascular lesions; laser; PDL; Nd:YAG; PDT

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## Introduction

Lasers were first used for the management and treatment of vascular lesions in the 1960s. During the past two decades, significant advances are evidenced, regarding laser application in dermatology and for the treatment of vascular lesions, in particular. An important breakthrough was the application of selective photothermolysis, the theory of which was first formulated by Anderson and Parish in 1983. According to this theory, when the laser beam contacts the vascular target, histologically selective vascular injury with coagulation is observed, together with vessel wall necrosis and perivascular collagen damage, while the associated thermal effects on the skin and the surrounding dermis are minimal[1].

Today there are various types of lasers used in dermatology. Pulsed dye laser (PDL) causes selective elimination of the vessel, leaving intact both normal epidermis and dermis. In addition, there are potassium titanyl phosphate laser (KTP), as well as infrared spectrum lasers such as alexandrite laser, diode laser, and neodymium-doped yttrium aluminium garnet laser (Nd:YAG). More recently, the combination of laser and photodynamic therapy (PDT) has also been employed for the treatment of vascular lesions.

The employment of lasers for the treatment of cutaneous vascular lesions constitutes one of their most popular applications. This review focuses on the use of lasers for the management of cutaneous vascular lesions, and discusses the data produced in recent research studies. For the purpose of this review, the categorisation of vascular lesions according to their time of onset—*i.e.* the distinction between congenital and acquired vascular

lesions[2], which can be managed with the use of lasers—will be used.

## Selective photothermolysis theory

The theory of selective photothermolysis, initially introduced by Parrish and Anderson in 1983[1], describes both the selective tissue damage as well as the minimum energy requirements for target destruction. More specifically, the theory of selective photothermolysis specifies that a chromophore may be targeted and damaged without causing significant injury to the surrounding tissues in the sense of a collateral damage. The variations in terms of wavelength (nanometres, or nm), fluence (energy density, or J/cm$^2$), beam diameter (spot size), and pulse durations (ms) result in the controlled thermal injury of the target tissue and the alterations in terms of penetration depth[2].

To achieve selective photothermolysis, four conditions should be fulfilled: (a) appropriate wavelength of the beam so as to be absorbed much more by the target chromophore than by the surrounding tissue and to achieve the deepest possible penetration, (b) adequate energy density of the beam so that to cause a non-reversible damage to the target, (c) pulse duration smaller than the thermal relaxation time (TRT), which is proportional to the size of the diameter of the chromophore-target, and (d) the largest possible beam diameter so that to achieve deeper penetration.

In the case of vascular lasers, the main chromophore-target is intravascular oxyhaemoglobin and, to a lesser extent, deoxyhaemoglobin and methemoglobin[3]. Haemoglobulin absorbs best in the blue, green, and yellow spectrums (418, 542, and 577 nm, respectively). It also presents an absorption peak in the near-infrared range (700–1100 nm). The challenge when treating vascular lesions is that melanin also shows a similar absorption profile at shorter wavelengths. Therefore, for patients with darker skin (Fitzpatrick skin types IV to VI), longer wavelengths should be preferred in order to avoid complications such as hyperpigmentation.

Fluence (energy per unit area) is inversely proportional to the fraction of light absorbed by tissue. The deeper in the dermis the target lies, the higher the required fluence will be. In addition, in cases where the chosen wavelength is only poorly absorbed by the target, high fluence is also necessary.

Pulse duration should strictly be shorter or close to the target's TRT. For example, the TRT for larger vessels such as leg veins will range in hundreds of milliseconds, whereas for facial telangiectasia will range in tens of milliseconds. Lastly, as far as the beam diameter is concerned, the larger the spot size, the deeper the penetration and the less scattering of the beam will be.

A 2004 publication noted the lack of comparative studies on laser efficacy/safety for the treatment of cutaneous vascular lesions[4]. Since then, more side-by-side studies have taken place. This article reviews up-to-date concepts on laser treatment of vascular lesions both in adults and children. It presents the most common vascular lesions amenable to laser treatment and highlights the keys in choosing the most efficient laser device for each case.

## Types of vascular lasers and energy-based devices

Among the first lasers to be used were continuous wave (CW) lasers such as argon laser[5]. These laser devices were widely utilised for the treatment of cutaneous vascular lesions but, apart from their relatively poor effectiveness on treatment, another main preventive side effect was the higher risk of scarring due to the long exposure durations. Today, with the continuous technological advances, they are no longer useful, as they pose a high risk of adverse effects such as dyschromia and scarring[2]. They have been replaced with quasi-CW mode lasers and pulsed laser systems that present lower risks and fewer side effects.

### Flash-pumped PDL

The Flash-pumped PDL is the most commonly used laser for most types of vascular lesions. PDL emits a pulsed beam at 585 nm wavelength (yellow light). A rhodamine dye dissolved in a solvent is pumped by a flash lamp. PDL maintenance is demanding, requiring annual service and replacement of the lamp and dye if necessary. The machine has to be switched off at least once per day to allow dye circulation.

The first PDL emitted a wavelength of 577 nm with fixed pulse duration of 0.45 ms. This short pulse duration, having had the small spot size, with high fluence as well as short wavelength and with limited depth penetration, produced very high complication rates including purpura and scarring. Current PDL emits at the spectrum of 585–600 nm with variable pulse durations, ranging from 0.45 to 40 ms. The longer pulse durations match better the feeding vessel's size and at the same time allow epidermal cooling, hence reducing risk of side effects. Spot sizes are available in the range between 3 to 12 mm and maximal energy fluence, depending on spot size, of 40 J/cm$^{2.}$ PDL is safe for children and infants.



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## Neodymium:yttrium-aluminium-garnet laser

Neodymium:yttrium-aluminium-garnet (Nd:YAG) laser emits in the near-infrared range of the spectrum at 1064 nm. The long wavelength enables deeper penetration while being much less absorbed by the competing chromophore-melanin. Therefore, Nd:YAG is the laser of choice for the treatment of vascular lesions of patients with darker skin types (Fitzpatrick IV to VI). It is also preferred for the treatment of deeper and resistant larger vessels. There is a relevant risk of scarring and blistering.

A spot selection (3, 5, 7, and 10 mm), with variable pulse duration (0.1–300 ms) to adjust to different vessel diameters, is available. High fluences (14 J/cm$^2$ up to 300 J/cm$^2$) and optimal cooling systems to avoid pain or burning should theoretically be effective for the treatment of most vascular lesions. The clinical endpoint is the clearing of the vessel immediately after treatment or colour change on the vessels.

On Q-switched mode, Nd:YAG produces two wavelengths: one in the infrared range (1064 nm) and a second beam of 532 nm wavelength, which is useful for superficial skin lesions and which acts similarly to the KTP. This is done with the adjustment of a potassium titanyl phosphate crystal. All the parameters should be individualised and accordingly applied based on the skin type and the history and nature of the lesion.

## Potassium titanyl phosphate laser

Potassium titanyl phosphate (KTP) lasers belong to the quasi-continuous lasers and emit at the 532 nm wavelength. Spots available are up to 5 mm and pulses durations range from 1–150 ms. Fluences up to 240 J/cm$^2$ are available. The main restriction with KTP is that melanin is a strong competing chromophore along with haemoglobulin at this short wavelength. Therefore, KTP is only suitable for skin types I–III. KTP is mainly used for small facial telangiectasia.

## Broad-band light sources: Intense pulse light

Intense pulse light (IPL) sources use a xenon flash lamp powered by a capacitor bank. IPL emit wavelengths between 515 and 1000 nm. This polychromatic energy makes IPL versatile and useful for the management of multiple skin conditions, both vascular and pigmentation disorders. In addition, their large spot sizes make them efficient for the treatment of extensive lesions.

## Photodynamic therapy

Photodynamic therapy (PDT) involves the exposure of skin to a light source after the effect of a photosensitising agent. The agent can be applied topically or be administered orally or intravenously. The photosensitiser, after being exposed to light, reacts with local oxygen and generates cytotoxic reactive oxygen species and subsequent tissue injury. The main benefit of PDT is that the low optical powers do not cause any epidermal injury, minimising risk of scarring and permitting treatment of all skin types.

# Vascular lesions

Dermatologists encounter a wide range of cutaneous vascular lesions. These are divided into two categories: congenital and acquired. This categorisation is important for the initial assessment and the final choice of the treatment method. An overview of the most common types of congenital and acquired vascular lesions can be seen in **Table 1**.

## Congenital vascular lesions

Congenital vascular lesions include haemangiomas as well as port-wine stains (PWS). As far as the differential diagnosis among the congenital cutaneous vascular lesions is concerned, **Table 2** presents briefly the differentiation elements between haemangiomas and PWS[6].

**Table 1.** Vascular lesions

| Congenital vascular lesions |
|---|
| • Infantile haemangiomas |
| • Port-wine stain (PWS) |
| **Acquired vascular lesions** |
| • Facial telangiectasia |
| • Leg telangiectasia |
| • Rosacea |
| • Poikiloderma of Civatte |
| • Spider angioma |
| • Pyogenic granuloma |
| • Venous lakes |



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**Table 2.** Differential diagnosis of congenital vascular lesions

| Characteristics | Haemangiomas | Port-wine stains |
|---|---|---|
| **Present at birth** | 30% | 100% |
| **Incidence by the age of 1 year** | 10%–12% | 0.3%–0.5% |
| **Female: Male ratio** | 3:1 | 1:1 |
| **Endothelial cell proliferation** | Quick | Normal |
| **Clinical course** | Rapid growth far above the normal development rate of the infant (Proliferation phase) | Growth proportional to the rate of normal development |
| **Prognosis** | Slow gradual involution, perfect or imperfect (Involution phase) | No involution, on the contrary, they worsen |
| **Localisation on the face or neck** | 60% | 85%–90% |
| **Heredity** | None | Multifactorial |
| **Complications** | • Ulceration, inflammation, bleeding<br>• Obstructive phenomena *e.g.* convergent amblyopia, and permanent refractive abnormalities, hearing, feeding, urination, defecation problems, etc. | • Glaucoma, seizures<br>• Tissue and/or bone hypertrophy |

## Cutaneous haemangiomas

Infantile haemangiomas (IH) are proliferating embryonal tumours, which can stem from placental tissue and are constituted by endothelial cells that hyperproliferate. Haemangiomas are the most common benign tumours in childhood, with their prevalence estimated to be up to 10%–12% in Caucasian infants, whereas they are less common in African and Asian children. The incidence is three times higher in females and especially in premature infants, as both the lower gestational age and the lower birth weight are associated with the development of the tumour[3].

The characteristic feature of haemangiomas is an early and rapid growth proliferation phase, followed by a stabilisation phase and a slow spontaneous regression phase, while during proliferative phase, 80% of all haemangiomas is doubled compared to their initial size[7]. In addition to this, these lesions may cause functional disorders, haemorrhage, and ulceration, while they may also lead to a secondary infection and aesthetic deformity[2,8-10].

Regarding the treatment of infantile haemangiomas, the optimal choice may depend on many factors, which should be taken into consideration by the dermatologist. Among these factors are the anatomic location; the size, the depth, the phase of the lesion; the age of the patient; the physician's experience; as well as the availability of a particular therapeutic approach[11–15]. It is also very important to inform the parents that 90% of haemangiomas will involute slowly after the age of 1 and may completely regress by the age of 9. Therefore, many parents may choose to wait and see how the lesion will progress.

In cases where treatment is decided, however, argon laser was among the first lasers to be used in the past with good results but it caused increased risk of scarring due to exposure to continuous wave[16,17]. Nowadays, the most widely used laser for the treatment of infantile haemangiomas is PDL; less often, both Nd:YAG and diode lasers are also used[18,19]. PDL is the most commonly studied laser type for IH[20], whereas Nd:YAG application is nowadays receiving a lot of attention.

According to a recent retrospective study conducted in New York, the use of 595-nm long-pulsed PDL (LPDL) with dynamic epidermal cooling was found to be particularly effective. Specifically, a total number of 90 infants were included with a median age of 3.0 months with a total number of 105 haemangiomas, and were treated



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using this particular laser device. The results showed that complete or near-complete clearance was achieved for 81% of the haemangiomas in terms of colour and 64% in terms of thickness[21].

Similar results were also found by a study conducted in Korea, in which a total number of 239 patients with skin types II–V participated and of whom, 37 patients had haemangiomas, and the same variable-pulse PDL method was used. More specifically, among the patients with haemangioma, the male-female ratio was 1.0:3.1; and for more than half of them (54.1%), good to excellent responses were achieved. Variable-pulse PDL proved effective and safe for darker skin types. As noted by the investigators, the best clinical response was observed in superficial haemangiomas in comparison to deep haemangiomas. Moreover, the lesions of younger patients responded more favourably than those of older patients[22].

In addition to these observations, a randomised controlled trial, in which 52 infants aged 1–3 months participated, showed that LPDL is more effective and significantly safer than PDL. In the aforementioned study, the infants were divided into two groups: one treated with PDL ($n$ = 26) and the other ($n$ = 26) treated with LPDL. In both occasions, the laser was combined with the use of epidermal cooling devices. Each group received treatment every four weeks until lesion clearance, and the outcome was assessed at the age of one year old. The assessment included clearance rate, time period of maximum proliferation, and complications. According to the results, at final assessment, 54% of the patients following treatment using the PDL showed complete clearance or minimal residual signs, while the corresponding percentage for the group of children following treatment with the LPDL was 64%. Although this difference was not statistically significant, the group treated with PDL had significantly more hypopigmentation (3.12% *vs.* 8.31%; $p$ = 0.001), more hyperpigmentation (2.8% *vs.* 4.15%; $p$ = 0.005), and more textural changes (1.4% *vs.* 6.23%; $p$ = 0.001). Finally, the average time period of maximum proliferation in the LPDL group was significantly shorter[23].

Recently, a comparison study was carried out in order to identify the earlier regression, the prevention of further proliferation, and the achievement of a better cosmetic outcome using PDL treatment in comparison to observation only ("wait-and-see approach"). A total number of 22 infants participated in the study, aged up to six months old. The investigators concluded that there were statistically significant differences in terms of the haemangioma's red colour and the final cosmetic outcome at 12 months in the group of infants treated with PDL as compared to the "wait-and-see" group[24].

As far as the long-pulsed ND:YAG Laser (1064 nm) is concerned, it seems that this type of laser is a safe and efficacious treatment for infantile haemangiomas, especially for older patients and superficial haemangiomas[25]. Combination therapy with PDL and Nd:YAG laser was also proved safe and effective in a German study[26].

The use of endolesional diode laser has also been shown to be effective in the treatment of infantile haemangiomas. A study conducted with the participation of a total number of 250 children, among whom 160 had haemangiomas, showed that the 980 nm diode laser used endolesionally is useful and effective in terms of cosmetic outcome and lesion clearance. Furthermore, among all paediatric patients of the study, only 38 required a second treatment session in order to achieve successful treatment, irrespective of their type of lesion[19]. Diode laser seems also to be useful for the treatment of remaining telangiectasia following haemangioma involution[27].

Finally, according to a retrospective study, the combination of PDL and propranolol resulted in better clearance of infantile haemangiomas, using a smaller total dose of propranolol to achieve almost complete clearance in comparison to the treatment method of propranolol followed by PDL or using propranolol alone[28].

## Port-wine stains

Port-wine stains (PWS) are the most common congenital vascular malformation with a prevalence of 3%[29]. PWS indicate capillary extension and histopathological deformations. A number of vessels dilate, reaching a diameter of 10 to 150 μm, involving predominantly the papillary or the upper reticular layer of the dermis at a depth of 300 to 600 μm[30,31].

The main difference between PWS and haemangiomas is that PWS have persistent pathological changes with no tendency to resolve with ageing. Therefore, it is recommended that PWS are treated as early as possible due to the probability of greater aesthetic disfigurement as well as the possibility of great psychological distress for the patient, usually a child at school age.

Argon laser was one of the first lasers to be applied on cutaneous lesions with a 488–514-nm wavelength that was well absorbed by oxyhaemoglobulin. However, the cutaneous wavelength was responsible for increased risk of side effects such as scarring and dyspigmentation[32].

During the past two decades, the use of lasers for the treatment of PWS has been extensively studied, and it has been found that PDL constitutes a highly effective and safe method as compared to other methods, due to the fact that the laser beam is only absorbed by the



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vessels, resulting in their selective damage and leaving the surrounding tissues intact. PDL was firstly developed for the treatment of PWS and for many years it has been the treatment of choice[8,10,33], since it results in a better outcome as compared to Intense Pulsed Light (IPL)[34]. However, the more mature (hypertrophic and nodular) PWS usually respond less adequately to treatment[2,8]. These are mostly observed in older patients and their treatment may be particularly difficult in many cases due to the greater depth of the vascular lesion[35,36].

The treatment of PWS using lasers is more effective when conducted during the first year after birth, which can partly be explained by the fact that the infant's skin is thinner, allowing greater penetration of the laser[37]. During the subsequent stages of PWS's development, treatment is not effective and sometimes resistance to treatment is observed. In such cases, the application of lasers at longer wavelengths and pulse durations has been studied[38].

As far as hypertrophic PWS previously resistant to PDL treatment are concerned, the use of long-pulsed alexandrite laser (LPPAL) (755 nm) has been proven useful when used alone[39] or in combination with PDL[40]. A relative risk of depigmentation when using LPPAL has been noted. In the case of concurrent use of PDL and LPPAL, a better outcome is achieved in less time and the reduction in terms of lesion colour is more profound without increasing the number of adverse events or complications[40].

In a side-by-side study, PDL and long-pulse Nd:YAG laser (1064 nm) were compared in regard to PWS treatment. A total number of 17 patients with PWS participated and it was shown that Nd:YAG is as effective as PDL when used at minimum purpura dose (MPD)[41]. When MPD is exceeded, the risks of side effects also seem to increase.

A further study with 25 participants supported the combined use of PDL (595 nm) and Nd:YAG (1064 nm), concluding that the aforementioned combination constitutes an effective treatment method for persistent PWS which do not respond to PDL treatment alone. Its adverse events were limited to temporary erythema, oedema, and purpura to a much lesser extent[9]. Nodular elements of PWS also seem to respond better to the concurrent treatment with PDL and Nd:YAG laser as the longer wavelength enables deeper penetration[42].

According to a recent study, the effectiveness of Nd:YAG laser (1064 nm) could be further improved by a potential optimisation of its effect on PWS. Experiments in albino rats, in which PEG-modified gold nanorods were intravenously injected, proved light absorbance to the laser by the blood to be significantly enhanced, thus addressing one of the method's limitations[43].

Lastly, a study in 2016 looked into the histological differences between PWS of lateral and central face, aiming to explain why lateral facial PWS respond better to PDL than central facial PWS do. Biopsy results showed that vessels in the lateral regions were mainly located in the papillary dermis, whereas in the central regions they tend to expand deeper and run through the dermis into the subcutaneous tissue[44]. In general, however, PWS on the face tend to respond better to the treatment than lesions on the rest of the body[45].

As a whole, the treatment of congenital vascular lesions using laser has been proven to be effective when initiated during the first year of life, something that is partially explained by the fact that the infant's skin is thinner and better penetration of the laser beam within the lesion is achieved[37]. PDL remains the first treatment of choice for most patients with PWS, with desired clinical endpoint being light purpura presented immediately or within a few minutes post-treatment. The presentation, on the contrary, of a steel-grey post-operative purpura may be indicating that the fluence of treatment was higher than appropriate and, as a result, the risk of scarring or blistering is increased.

Regarding the expectations that the patients should have, both for PWS and haemangiomas, in relation to treatment success, usually six or more treatment sessions are required within a period of two years to achieve significant clinical outcome. For patients with PWS at specific spots on their body, such as the upper lip, more treatment sessions may be required while complete clearance may not be achieved.

## Photodynamic therapy and cutaneous PWS

In addition to the use of lasers, the application of photodynamic therapy (PDT) has also been studied for the treatment of PWS. According to recent studies, the combination of PDL and PDT using the topical photosensitising agent 5-aminolevulinic acid (5-ALA) seems to be effective in the treatment of PWS[42,46,47].

PDT involves the administration of a photosensitising agent and the subsequent exposure to light at a specific wavelength, resulting in the production of reactive oxygen species (ROS), which in turn leads to cytotoxic effects due to the oxidative damage of the surrounding cellular structures[48]. These cytotoxic ROS, a product of the reaction of the activated photosensitiser with local oxygen, can induce highly localised cellular or tissue damage[49].

Recently, the application of 5-ALA followed by 595-



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nm PDL irradiation was assessed for the treatment of recalcitrant PWS. More than half of the patients (65.71%) showed mild to moderate clinical improvement after three treatment sessions, while patients' discomfort over the entire course of treatment was similar to that of previous treatments with PDL alone[46]. A significant number of large research studies have been conducted in China, in which PDT was used for the treatment of cutaneous lesions. In a retrospective analysis, the data of 238 patients with PWS, who received treatment with photocarcinorin-mediated PDT using a copper vapour laser were presented. Following two to four treatment sessions using PDT, almost one-third of the patients (29%) showed particularly good outcome and slightly more patients (32%) showed good outcome, while poor response was evident for only 3% of the patients[50].

PDT effectiveness was also demonstrated in another longitudinal retrospective study, in which the data of 1,385 patients with PWS who followed PDT for the treatment of their vascular lesions were examined. The investigators concluded that PDT is an effective treatment method for all types of PWS. Usually, more than one treatment sessions are required to achieve a better cosmetic outcome, yet after only one PDT treatment session, almost half of the patients had an excellent or very good outcome and fewer than 10% of them had just a good outcome[51].

Moreover, in a side-by-side comparison of PDT and PDL for the treatment of PWS, it was shown that PDT is at least as effective and safe as PDL, or even superior in some cases, for the treatment of certain types of PWS[31]. Similar results were reported in another study, in which the investigators concluded that the combination of PDT (benzoporphyrin derivative monoacid ring A photosensitizer with 576-nm light) and PDL for the treatment of PWS is effective and contributes to the reduction of the total number of treatment sessions, while the number of adverse events, such as scarring, is also reduced[52].

Recommendations regarding the use of the various lasers in the treatment of congenital vascular lesions are summarised in **Table 3**.

## Acquired vascular lesions

Acquired vascular lesions that can be managed using lasers are classified into flat and papular. Among the flat vascular lesions, idiopathic telangiectasia, telangiectatic rosacea, linear telangiectasia of face-nose, Poikiloderma of Civatte, as well as leg telangiectasias are included. Among papular vascular lesions, spider angiomas, cherry angiomas, and angiokeratomas are included. In the following sections, the application of lasers for the treatment of certain acquired vascular lesions is discussed, while a summary of treatment recommendations for each condition is, soon thereafter, provided in **Table 4**.

### Telangiectasias

Telangiectasias are enlarged capillaries in the skin, visible to the naked eye, which usually occur on areas of the face and lower extremities. These superficial vessels have usually a diameter between 0.1 and 1 mm, and represent a dilated venule, capillary or arteriole. They are located underneath the epidermis and their colour usually varies from dark cyan to bright red. Depending on their appearance, telangiectasias are characterised as simple or linear, arborising, spider or star, punctiform, and papular.

Facial telangiectasias usually emerge on the central and lateral areas of the face[2]. Their aetiology and pathogenesis may be the result of various factors, including genetic predisposition, presence of other diseases, chronic sun exposure, surgical or physical trauma, corticosteroid use, pregnancy, oestrogen ingestion, etc. For the management of face and neck telangiectasia, irrespective of its type and extension, there are many advanced lasers operationally based on the selective photothermolysis principle (LPDL, KTP 532 nm, long-pulsed Nd:YAG), which ensure effectiveness.

Classic PDL has been extensively used for arborising telangiectasias, providing particularly good results in comparison to other light sources, but causing purpura reaction. In order to achieve treatment without inducing purpura reaction, the use of multiple applications of LPDL is required[53]. In a randomised controlled trial in which 39 patients participated, it was shown that LPDL was more effective than IPL in terms of vessel clearance. Apart from this, patients reported that they preferred this type of PDL as it was both more effective and caused less pain during the treatment session[54].

As far as KTP (532 nm) is concerned, it has been suggested that it is preferable in more distinct cases of linear telangiectasias. In a retrospective study, data of 49 patients with facial telangiectasia were examined and, following the treatment and the follow-up phases, complete or almost complete clearance was achieved in 90% of the patients. Based on the findings, the investigators concluded that this type of laser provides a safe and effective treatment of common superficial vascular lesions in patients with skin types I–III according to the Fitzpatrick scale[55].

Interesting findings were also yielded by another retrospective study that included the data of a large number of patients followed-up for three years, in relation to the treatment of superficial vascular lesions using Nd:YAG laser (1064 nm). Among 130 patients with facial telangiectasia who completed the study, 125 of them (97%)



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**Table 3.** Recommendations for the use of lasers for treatment of congenital vascular lesions

| Indication | Lasers | Remark |
|---|---|---|
| Infantile haemangioma | PDL, Nd:YAG, diode laser, IPL | • Involution noted at 90% of cases by the age of 9 years old.<br>• PDL is the treatment of choice.<br>• Deeper lesions: Nd:YAG. |
| PWS | PDL, IPL, Nd:YAG, LPPAL, PDT | • PDL is the most commonly used laser. Clinical endpoint: purpura.<br>• Deeper and popular lesions do not respond well to PDL.<br>• Nd:YAG is better suited for deeper lesions.<br>• Combination treatments should be considered in resistant cases.<br>• PDT has also proven to be effective. |

**Table 4.** Summary of recommendations for treatment of acquired vascular lesions

| Indications | Lasers | Remarks |
|---|---|---|
| Facial telangiectasia | PDL, LPDL, IPL, KTP, Nd:YAG | • PDL is the most commonly used laser.<br>• KTP is preferred for linear telangiectasia.<br>• Nd:YAG laser: larger vessels and darker skin types. Caution with periorbital area. |
| Leg telangiectasia | PDL, Nd:YAG | • Nd:YAG is the treatment of choice. |
| Rosacea | PDL, LPDL, IPL | • LPDL is the treatment of choice.<br>• IPL: shorter "downtime'' after treatment. |
| Poikiloderma of Civatte | KTP, PDL, Ablative Fractional Lasers | • Extra caution due to mixed features of telangiectasia and hyperpigmentation. |
| Spider angioma | PDL, Nd:YAG KTP | • PDL is the treatment of choice. |
| Pyogenic granuloma | PDL, Nd:YAG, $CO_2$ | • Increased risk of recurrence. |
| Venous lake | Nd:YAG, PDL, diode laser, KTP | • Nd:YAG shows better results than PDL |

showed significant improvement or complete clearance. However, this method is not recommended to be the first choice for facial telangiectasia, if vessels are not so deeply located. In the same study, it was also shown that among 99 patients with telangiectasia of the lower extremities who completed the study, 80 of them (80.8%) showed significant improvement or complete clearance[56].

Finally, it is important to acknowledge the results of a recent study, which intended to assess the effectiveness and safety of a micropulse 1064 nm Nd:YAG laser for the treatment of facial telangiectasias. A total number of 20 patients participated in the study, and their status was assessed following the completion of two treatment sessions using the aforementioned laser device. According to the assessment by an independent researcher, satisfac-



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tory clearance was achieved in 75% of patients and complete clearance was evident in as many as 10%, while no patient was reported as having no clearance at all, or worsening or experiencing adverse events. Therefore, the investigators concluded that micropulse 1064 nm Nd:YAG laser is both safe and effective for the treatment of facial telangiectasia[57].

As far as the treatment of telangiectasias of the lower extremities using Nd:YAG laser is concerned, a model has been suggested, in accordance with the best treatment outcome achieved using a range of moderate fluences (100–200 J/cm$^2$) and pulse durations between 10 and 100 ms, in order to reduce excess dermis heating and pain[58]. Similar conclusions were reached in a recent study, according to which multiple treatment sessions, spaced 8 to 12 weeks apart, are necessary to reduce the colour and the size of the lesion, as well as to improve the contour of the skin with minimal side effects. Commonly, complete clearance of smaller lesions is achieved, while the size of greater venous malformation is reduced following the application of many treatment sessions using Nd:YAG laser[59].

Srinivas and Kumaresan suggested that the best treatment option for telangiectasias of the lower extremities is achieved with 1064 nm Nd:YAG laser, as its leads to in-depth penetration (5–6 mm), reaching deeply located vessels such as these characterising this particular condition[60]. The use of this laser device was also proposed by other researchers for the treatment of deeper vascular lesions, who also underlined that to avoid overheating of the skin and textural changes, the use of a cooling devise is necessary[61]. The Nd:YAG laser is also a treatment of choice for telangiectasia of darker skin (Fitzpatrick IV–V), as the long wavelength enables deep penetration but minimum absorbance by melanin[62].

In general, the basic principles for laser application on linear or arborising telangiectasias concern the targeting of the vessel (vessel tracing method), the use of the appropriate beam diameter (seeking to achieve deeper penetration and reduce scattering), and the use of variable pulse range depending on vessels' size. In addition to these, the appropriate energy density should be applied to achieve irreversible damage of the target, which is determined by the skin phototype, the application, and the type of cooling device. The cooling device should be flexible and allow continuous visual contact as well as the presentation of the end-point. The end-point for vessels of small diameter relates to the direct clearance of thin telangiectasias and the immediate contraction of their wall. As far as the larger vessels are concerned, with a diameter of more than 0.3 mm, the end-point relates to the immediate presence of intravascular coagulation, which is detected through palpation. Conclusively, one to three treatment sessions are usually required for the treatment of telangiectasias, while using the appropriate laser.

## Rosacea

Rosacea is a chronic rash that is usually located in the midline of the face (nose, cheeks, forehead, periorbital, and chin), in which papules and crusts appear on red or erythematous skin. As the condition progresses, small vascular disorders of the skin may appear and eventually the sebaceous glands of the nose may swell, leading to malformations (rhinophyma). The condition is usual, especially in middle-aged persons from southern Europe. Women are affected more than men. According to many research studies, long-pulsed 595 nm PDL constitutes an effective method for the treatment of this condition, as well as the associated erythema and telangiectasia, with minimal adverse events and no long-term complications[63,64].

In one study, long-pulsed 595 nm PDL was used for the treatment of 20 patients with rosacea. Assessment was carried out using a scale from 0 to 6, in which 6 represented the most severe cases. A mean score of 1.4 was observed at the end of the treatment, showing a statistically significant reduction. The investigators concluded that this particular type of laser has very good results in the treatment of rosacea, while its safety profile is as favourable as the PDLs of older technology[63]. Similar were the results in another study, where LPDL was used for the treatment of rosacea-associated telangiectasia and no significant purpura reaction was observed after treatment[65].

Positive results have also been reported in relation to quality of life improvement for patients with erythematotelangiectatic rosacea who followed treatment using PDL. Specifically, a study employed the Dermatology Life Quality Index (DLQI), which was completed by the patients at the beginning and at the end of treatment. The results confirmed the statistically significant difference in the quality of life for all patients between baseline and after three treatment sessions when the final evaluation was recorded[64]. Similar results were demonstrated by Shim and Abdullah, through another similar study of patients with erythematotelangiectatic rosacea, who completed the DLQI. After three treatment sessions, the difference in terms of quality of life, as assessed by patients at the beginning and at the end of treatment, was statistically significant, with a better score after treatment[66]. Lastly, IPL has also been proven safe and effective for treatment of rosacea-related erythema and



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increased blood flow, as demonstrated by scanning laser doppler[67].

### Poikiloderma of Civatte

Poikiloderma of Civatte is a common condition that mostly affects women, particularly those with history of cumulative sun exposure. The sides of the neck are affected, causing erythema, diffuse telangiectasia combined with hyperpigmentation, and reticular wrinkling or even atrophy. Treatment may be achieved using a single or combinations of various types of laser, including KTP and PDL, to restore both the natural colour and the texture of the skin. Nevertheless, complete clearance of this condition may be challenging, while certain adverse events have also been reported, such as hypopigmentation and erythema above normal levels[60,68].

In a study including 8 patients, most of whom were women, 585 nm PDL was used at a constant pulse duration of 450 μs. The investigators concluded that the result was good in terms of vascular lesion clearance. Nevertheless, 6 of the patients who followed treatment using a fluency between 5 and 7 J/cm$^2$ reported severe depigmentation 4 to 11 months after treatment completion, something that was not the case for those who followed treatment using a lower fluency between 3.5 and 5.5 J/cm$^2$. Therefore, PDL for the treatment of Poikiloderma of Civatte should be carefully applied, while further studies are needed to further evaluate the best method of application[69]. As mentioned in the recent guidelines by the European Society for Laser Dermatology (ESLD), special attention should be given in areas with hyperpigmentation, as well as in areas prone to scarring such as the anterior chest or neck[2].

Lastly, a recent study among Caucasians patients showed good results in the treatment of both the vascular and the hyperpigmentation components of Poikiloderma of Civatte with ablative fractional laser resurfacing, which was accompanied by significant changes of skin texture and laxity[70].

### Spider angiomas

The use of various lasers has also been studied in relation to the treatment of smaller cutaneous vascular lesions such as the spider angioma. A characteristic of spider angiomas is their “elevated” papular central part, from which capillaries radiate outwards and gradually expand like a spider’s web. It is a common condition in children but it may also appear in adults following pregnancy or on the background of liver disease.

The results of a retrospective study, in which the data of 58 patients with spider angiomas were examined, showed that 98% showed complete or almost complete clearance at the end of the treatment with KTP 532 nm and follow-up periods[55]. Moreover, PDL (595 nm) is also suggested for the treatment of spider angiomas, although it is noted that a number of treatment sessions are necessary[71]. Furthermore, in a prospective study, carried out in the United Kingdom with the participation of a total number of 201 patients with spider angiomas, it was found that lesion clearance occurred in 95% of them regardless of anatomic site. An average number of 1.84 treatment sessions using PDL were required, with a maximum number of 7 treatment sessions for a small number of patients, while for larger lesions, more treatment sessions were necessary[72]. Lastly, the successful employment of 1064 nm Nd:YAG laser has also been reported. In a follow-up study of 3 years, all 26 patients with spider angiomas were treated and experienced significant clearance with minimal pain, although the results were less encouraging in the instance of neck and hand areas[56].

### Pyogenic granulomas

A pyogenic granuloma, also known as lobular capillary haemangioma, is a common benign tumour of the skin and mucous membranes, characterised histologically by great accumulation of capillary blood vessels, which are surrounded by connective tissue and filtered by inflammatory cells[73]. Bleeding is also very common, even in cases of minor injury, while many times they emerge during pregnancy or following injury[74].

Both 585 nm PDL and Nd:YAG lasers have been used for the treatment of pyogenic granulomas. As far as the use of PDL is concerned, the results of a study, in which 18 patients with symptomatic pyogenic granulomas at different parts of their body participated, indicate that it leads to effective treatment for the majority of patients. In particular, 88.9% of the patients demonstrated both symptomatic and clinical clearance of the lesions, with excellent cosmetic results after treatment[75].

In a more recent retrospective study, the application of Nd:YAG laser for the treatment of pyogenic granulomas was tested. In this study, the data of 25 patients were examined and it became evident that the application of Nd:YAG laser (1–14 pulses, 100–130 J/cm$^2$) was effective in clearing these lesions in the majority of patients[76].

Apart from PDL and Nd:YAG lasers though, $CO_2$ laser is also applied for the treatment of pyogenic granulomas. A recent study has reported successful and safe $CO_2$ laser-assisted surgical excision of a pyogenic granuloma from the oral cavity of a pregnant woman with-



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out complications[77]. More importantly, a 10-year retrospective study comparing the surgical removal of pyogenic granulomas, with either the classical method followed by suture, or with employment of a $CO_2$ laser, concluded that the latter, should be the first-choice treatment for the ablation of pyogenic granulomas, as its recurrence rate was zero. Although, researchers were aware of recurrence issues reported in past studies, they considered those containable with proper decision-making[78].

### Venous lakes

Venous lakes are a form of senile angioma, which usually occurs on the face, lips, and ears of elderly patients. Histologically, venous lakes consist of greatly dilated, thin-walled venules without the proliferation of vascular tissue of the true angioma.

Among the first choices of laser devices for the treatment of venous lakes are both KTP and Nd:YAG lasers, as mentioned in the recent guidelines by the European Society for Laser Dermatology (ESLD)[2].

A study, in which 35 patients with venous lakes were included, showed that following only one treatment session, complete clearance of the lesion was observed in 94% of the patients and no relevant complications were reported. The investigators concluded that long-pulsed Nd:YAG laser is highly effective for the treatment of venous lakes of the lips and cheeks[79].

The combination of 595 nm PDL and 1064 nm Nd:YAG laser has also been found to be effective. More specifically, in a study with the participation of 30 patients, the degree of resolution of a total number of 39 venous lakes was assessed. The treatment was initially carried out using PDL (at 20 ms and 10 J/cm$^2$) followed by Nd:YAG laser (at 20 ms and 70 J/cm$^2$). The investigators reported complete clearance of 38 lesions (95%) and no post-treatment complications, with the exception of one patient who had a small scar. Therefore, they concluded that the combined application of both of the aforementioned lasers provide a safe, fast, and effective option in the treatment of venous lakes[80].

Finally, effective clearance of venous lakes may also be achieved using diode lasers. More specifically, in a recent study, in which 17 patients with venous lakes of the lips participated, 808 nm diode laser was used for treatment. The results showed that even after one single treatment session, all lesions were successfully treated. Healing was achieved after approximately two to three weeks, and none of the patients experienced complications, while post-operative discomfort and scarring were not present or minimal[81].

## Conclusion

The present literature review of recent research articles, regarding laser use for the management of cutaneous vascular lesions, proposes that successful ment can be achieved through the application of the various available laser devices. It is the authors' opinion that PDL is the most frequently used laser at the moment for the treatment of vascular lesions, offering a wide range of treatment applications. In general, with all current available equipment, vascular lesions can be satisfactory treated at a range of 80–90%, when addressed at early stages.

New technologies with the combination of some machines that are able to produce two wavelengths are likely to optimise the treatment results. Enhancement in epidermal protection methods, such as cooling devices[82], in order to minimise risk of thermal injury and pigmentation disorders will further allow a better outcome to be obtained even for darker skin types. Progress in the field of supplementary treatments (ß-blockers and chemotherapy drugs) are expected to further improve both the effectiveness and safety of these treatment methods in the near future.

To conclude, modern applications of lasers in dermatology constitute one of the most promising methods for the management of cutaneous vascular lesions, combining the advantages of invasive therapy with the safety of non-invasive therapy, while in certain cases lasers are the only way to treat these lesions. The continuous research on laser application for the treatment of the various types of vascular lesions—both congenital and acquired—and the combination of the existing systems guarantee particularly good results, as long as they are applied by specialised and experienced dermatologists. Careful assessment of the history of the lesion, the skin type, and the tissue response will enable the design of an individualised treatment protocol aiming for the best outcome.

## Conflict of interest

The authors declare no potential conflict of interest with respect to the research, authorship, and/or publication of this article.

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