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Authors
Kelly, KM
Nelson, JS

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Update on the Clinical Management of Port Wine Stains

K.M. Kelly and J.S. Nelson
Departments of Surgery and Dermatology, Beckman Laser Institute and Medical Clinic, University of California, Irvine, USA

Abstract. Port wine stains (PWS) are congenital vascular malformations for which lasers are the treatment of choice. This article reviews laser optics in relation to PWS treatment and discusses the major laser and light source systems, including the flashlamp-pumped pulsed dye laser (FLPDL), cryogen spray cooling in combination with the FLPDL, the potassium titanyl phosphate (KTP) laser and the intense pulsed light source, currently utilised for this procedure. Future opportunities for therapeutic improvement are also considered.

Keywords: Laser treatment; Port wine stain

INTRODUCTION

A port wine stain (PWS) is a congenital vascular malformation found in approximately 0.3% of infants [1]. PWS are generally noted at birth as faint pink macules which, as the child ages, thicken and darken to a red–purple colour. About 5–8% of facial PWS birthmarks are associated with other abnormalities including glaucoma [2]. Histologically, PWS consist of dilated, capillary-like vessels in the dermis with no endothelial proliferation [2].

PWS may be located anywhere on the body but are commonly found on the face and neck where they may have serious psychological consequences. Patients are often perceived by others as 'marked' which may adversely affect personality development. For this reason, and because PWS do not involute spontaneously, patients or their families seek medical intervention. In the past, treatment options included cosmetics, skin grafting, radiation, dermabrasion, cryosurgery, tattooing and electrotherapy none of which provided good cosmetic results. Lasers offer a safe and effective option and have become the treatment of choice.

Correspondence to: K. M. Kelly, MD, Beckman Laser Institute and Medical Clinic, University of California, Irvine, 1002 Health Sciences Road East, Irvine, CA 92612, USA. Tel.: +1 (949) 824-8020; fax: +1 (949) 824-8413.

LASER OPTICS IN PWS TREATMENT

Optimal laser therapy for PWS birthmarks requires selectively injuring the blood vessels in the dermis while sparing the overlying epidermis. Several laser parameters are relevant to achieve this objective. First, to obtain selective damage, the laser wavelength must approximate an absorption peak of the targeted chromophore in relation to other optically absorbing molecules in the overlying epidermis or surrounding dermis [3]. Oxyhaemoglobin (HbO_2) with absorption peaks at 418, 542 and 577 nm is the targeted chromophore in PWS vessels. The Soret band at 418 nm has the highest absorption peak and thus might be considered the optimal choice for laser therapy. However, this wavelength can be rejected for clinical use on the basis that penetration of the photons into the dermis is insufficient to produce blanching of PWS vessels deeper than 0.1 mm from the skin surface. Optimum treatment requires coagulation of the vascular plexus to a depth of at least 0.5 mm [4]. Many of the lasers developed for PWS treatment utilise a wavelength slightly longer than one of the absorption peaks, achieving acceptable haemoglobin absorption while penetrating deeper into the dermis and individual vessels. Moreover, the absorption spectrum of melanin, the major competing chromophore in the epidermis, increases

proportionally at shorter wavelengths [5]. Thus, most lasers used to treat PWS use wavelengths in the 532–600 nm range.

Second, the pulse duration of laser exposure must approximate the targeted chromophores thermal relaxation time, the time required for the heat generated by the absorbed light energy within the target to dissipate to 50% of its value immediately after laser exposure [3]. The thermal relaxation time is proportional to the size of the targeted entity squared. PWS vessels are generally 30–170 μm in diameter and thus, pulse durations of 1–13 ms are considered optimal for treatment [4,6], minimising heating of non-vascular tissue while allowing sufficient time for damage of the vessel wall without vaporisation. When longer pulse durations are utilised, heat diffuses from the targeted structure to adjacent tissues possibly resulting in adverse effects. Very short pulse durations can cause sudden erythrocyte vaporisation, which results in vessel rupture and temporary purpura [6]. The skin can repair this type of injury over 7–14 days but the blue–black discoloration of the skin during this period is unsightly and may cause patient embarrassment.

Third, laser energy must be sufficient to coagulate PWS blood vessels. The blood must be heated to approximately 70°C for irreversible vessel destruction [5]. Too much energy, even when delivered at the desired wavelength and pulse duration may produce residual heat, injuring surrounding structures and possibly resulting in adverse effects [7].

Finally, the spot size or area irradiated with each laser pulse must be considered. Larger spot sizes provide several advantages including: (1) more rapid treatment; (2) more uniform energy transmission; and (3) greater central photon density with less marginal photon loss which allows greater vessel damage at lower energy densities [7].

An early development was the argon laser. Unfortunately, this laser's blue–green light (488, 514 nm) did not match any of the HbO_2 absorption peaks and at these relatively short wavelengths, there was significant melanin absorption, which resulted in epidermal blistering and damage. Furthermore, until recently, the shortest pulse duration available in argon lasers was 0.05 s. Heat dissipation from the treated blood vessels resulted in additional epidermal injury as well as damage to non-targeted dermal components including collagen.

Because of this non-specific injury, it is not surprising that adverse effects were common after argon laser treatment of PWS birthmarks. Hypertrophic scarring occurred in up to 40% of young infants and children [8,9]. Atrophy and cutaneous depressions were even more prevalent [10]. As a result, the argon laser is rarely used for PWS treatment except for occasional nodular lesions in adults.

Within the past decade, several lasers have been developed using longer wavelengths and longer pulse durations. In addition, cooling devices have been added to protect the epidermis allowing the use of higher fluences for better PWS vessel destruction (Table 1).

THE FLASHLAMP-PUMPED PULSED DYE LASER

The flashlamp-pumped pulsed dye laser (FLPDL) is the current treatment of choice for most PWS lesions. Ashinoff and Geronemus [11] reported that 75% of patients achieved 50% PWS lightening with this laser. Current models such as Candela Corporation's (Wayland, MA) SPTL-1b utilise yellow light with a wavelength of 585 nm and pulse duration of 450 μs. The 585 nm wavelength, although not one of the HbO_2 absorption peaks was determined to be optimal as it allows a greater depth of penetration (1.20 mm at 585 nm versus 0.50 mm at 577 nm) while maintaining nearly the same degree of vascular specificity [12]. The pulse duration is only slightly shorter than the thermal relaxation time of the PWS blood vessels, resulting in good vessel coagulation. Vessel wall rupture does occur resulting in temporary (7–14 days) post-treatment purpura.

Treatment in infants and young children is initiated at 5–6 J/cm^2 with a 7–10 mm spot size and increased by 0.50 J/cm^2 with each treatment if no adverse effects are noted. In adults, higher fluences (6–8 J/cm^2) may be utilised. The FLPDL can achieve a maximum energy density of 10 J/cm^2.

During laser treatment, the hand-piece is moved in a methodical fashion across the PWS. Best results are achieved when pulses are overlapped by 10%, thus avoiding the checkerboard pattern of treatment seen when spaces are left between pulses. Spots are not overlapped on the neck and 'V' of the upper anterior chest, where blistering and subsequent scarring are more likely. In these

Table 1. Summary of light systems utilised for PWS treatment

Laser or light source	Wavelengths (nm)	Pulse duration (μs)	Spot size (mm)
FLPDL Model SPTL-1b Candela Corporation	585	450	2, 3, 5, 7, 10
FLPDL plus CSC ScleroPLUS® Candela Corporation	585, 590, 595, 600	1500	2, 3, 5, 7, 10 and 2 × 7
Photogenica VLS® Pulsed Dye Laser Cynosure	585, 590, 595, 600	450, 1500	3, 5, 7, 10
Potassium Titanyl Phosphate (KTP) Versapulse® Coherent, Inc.	532	2000–50 000	2, 3, 4, 5, 6
Aura KTP with Starpulse® Laserscope	532	1000–50 000	0.5, 1, 2, 4 scanner with spot size up to 13 mm
VeinLase® HGM	532, 1064	8000–50 000	2, 4
Intense Pulsed Light Source Photoderm® Sharplan-ESC Medical Systems Ltd	515–1200	500–25 000	8 × 35, 8 × 15

FLPDL, flashlamp-pumped pulsed dye laser; CSC, cryogen spray cooling.

locations, a 4–5 mm space is left between sequential pulses, to be filled in later during the same treatment session. The fluence is also decreased during treatment of these areas.

Patients may experience mild local swelling, erythema and postoperative pain often described as a 'sunburn' sensation. Ice packs, cooling soaks, and mild analgesics such as acetaminophen are generally all that is required for relief. The application of emollients such as aloe vera gel or Aquaphor Healing Ointment® (Beiersdorf Inc., Wilton, CT) may also be soothing. No wound dressings are required and there are no activity limitations following treatment. If scaling or crusting develops, patients are advised to apply a topical antibiotic ointment. To prevent hyperpigmentation, patients are instructed to avoid sun exposure to the treated area for three to six months. The PWS gradually lightens over several months post-treatment.

The safety of this laser for the treatment of PWS birthmarks has been documented by several studies [13–17] as well as our own extensive experience. Temporary hyperpigmentation occurs in up to 35% of patients [13–15] especially after treatment of lower extremity lesions but can be minimised by sun avoidance pre- and post-treatment. If desired, resolution can be hastened by using topical hydroquinone or kojic acid. Hypopigmentation occurs in less than 1–2% of patients [14,16]. Scar formation, generally atrophic rather than hypertrophic, occurs in fewer than 5% of patients [14,16]. When they occur, hypertrophic scars can often be successfully treated with topical or intralesional steroids.

Occasionally, a pyogenic granuloma will develop resulting in persistent bleeding and requiring excision or curettage and desiccation. A mild eczematous dermatitis may develop in the treated area, which can be resolved with topical steroids [17].

DYNAMIC EPIDERMAL COOLING IN CONJUNCTION WITH THE FLPDL

Although the FLPDL has substantially improved PWS treatment, adverse effects still occur and the majority of patients achieve PWS lightening, but not complete blanching. Epidermal melanin acts as a barrier through which the laser light must pass before reaching the PWS blood vessels. Absorption of laser energy by melanin causes localised heating in the epidermis, which produces several of the complications associated with treatment including, dyspigmentation and scarring. Furthermore, epidermal melanin reduces the

light dosage reaching the blood vessels, thereby decreasing the amount of heat produced in the PWS and leading to suboptimal blanching of the lesion. One way to address the aforementioned problems is spatially selective photocoagulation, a term used to describe the concept of providing epidermal protection while still achieving thermal injury in the dermis.

In 1994, Nelson et al. [18–20] developed 'dynamic' or cryogen spray cooling (CSC) as an efficient and effective means of achieving spatially selective photocoagulation. A millisecond cryogen spurt is applied to the skin surface immediately before laser exposure allowing localised cooling of the epidermis without affecting the temperature of the deeper targeted blood vessels, leaving the latter susceptible to laser-induced thermal injury. Tetrafluoroethane ($C_2H_2F_4$; b.p.= -26.2°C) a non-toxic, non-flammable and FDA approved freon substitute is currently the cryogen of choice.

Candela Corporation's (Wayland, MA) ScleroPLUS® provides CSC in combination with a tunable dye laser offering a pulse duration of 1500 μs, wavelengths of 585–600 nm and round spot sizes of 2, 3, 5, 7 and 10 mm or a 2×7 mm elliptical spot for treatment of leg veins. The longer pulse duration allows treatment of larger blood vessels and, because the vessels are heated more slowly, results in less purpura. The longer wavelengths allow laser light to penetrate further into individual vessels and permit injury of vessels deeper in the vascular plexus.

One study using a FLPDL with a 450 μs pulse duration and no CSC demonstrated that in a few patients, 600 nm in combination with a mean fluence of 9.88 J/cm^2 could achieve better PWS clearing than 585 nm [21]. The researchers were not able to identify readily apparent PWS characteristics that would accurately predict optimal results with longer wavelengths. However, vessel size and depth are likely to be key factors.

A recently published investigation [22] utilising Candela's SPTL-1b FLPDL in combination with CSC demonstrated that this technology permits the use of higher incident laser light dosages which expedite PWS clearing. A total of 98 patients received laser therapy utilising fluences of 8–10 J/cm^2 with CSC and an additional 98 patients received laser therapy utilising fluences of 5–7 J/cm^2 without CSC. Standardised pre- and post-treatment photographs were evaluated by three plastic surgeons and graded for clearing using a scoring system where 1 indicated poor blanching (<25%) and 4 indicated excellent blanching (76–100%). After an average of 3–4 treatments, the mean blanching scores for patients who received laser therapy with and without CSC were 2.92 and 2.32, respectively, a statistically significant difference. No permanent scarring or hypopigmentation was observed in patients treated with CSC plus the FLPDL.

CSC decreases treatment pain [20,23,24] especially in patients with darker skin types. This benefit is less marked in children possibly because some of their discomfort is a result of anticipatory fear. Children may be afraid of the 'hiss' associated with the cryogen release; thus, the procedure should be demonstrated to them before beginning treatment. The duration of post-laser treatment purpura is also decreased with CSC, but the incidence of hyperpigmentation is unaffected [20,22,24].

Treatment is performed in a manner similar to that described for the FLPDL with some adjustments in laser parameters. For children and adults, we generally initiate treatment at 8–10 J/cm^2 with the 7 mm spot size and a cryogen spurt of 50 ms with a 10 ms delay between spurt termination and laser irradiation. Optimal values for the cooling parameters are dependent on the target (PWS vessel) depth, which of course will vary between patients and even between sites within a PWS. Our choice of cryogen spurt duration and delay are expected to achieve a good effect in a wide variety of vessels.

As discussed above, the treatment endpoint is light purpura (a reddish discoloration) rather than the blue–black seen with the traditional FLPDL; however, post-treatment wound care is identical.

Cynosure also offers a pulsed dye laser, the Photogenica VLS®, with wavelengths of 585–600 nm and pulse durations of 450 and 1500 μs. Cooling is provided by a device called Smart Cool, which blows cold air on to the skin. The efficacy of this new cooling modality is currently under investigation.

KTP LASER

A 532 nm wavelength is achieved when a potassium titanyl phosphate (KTP) crystal is placed in the Nd:YAG laser. This laser emits green light at a wavelength of 532 nm. The

KTP laser is offered by Coherent Inc. (Santa Clara, CA) in the VersaPulse® aesthetic laser system, Laserscope (San Jose, CA) in the Aura® laser system and HGM Medical Laser Systems in the VeinLase®. For some of these systems, a chilled sapphire plate can be added, which is cooled by circulating water. This offers some epidermal protection but the conductive cooling utilised by this system is less effective than the evaporative cooling available from CSC [25].

The KTP laser has been used extensively for treatment of telangiectasias of the face with good results and minimal side effects [26,27]. Dummer et al. [28] described use of the KTP laser for PWS birthmarks using fluences of 5–10 J/cm^2, pulse durations of 7–10 ms and a chilling plate temperature of 4–5.5°C. They reported 50% or greater blanching in 75% of patients after 1–3 treatments with no scarring or dyspigmentation. A few patients developed erosions in the treatment area. In our experience, the pulsed dye lasers achieve better results for the treatment of PWS birthmarks but we have also obtained some success with the KTP laser using the following parameters: radiant exposure 10 J/cm^2; spot size 5 mm; pulse duration 20 ms; temperature of chilled plate 4°C.

With the aid of ultrasound gel, the chilled plate/laser hand-piece is moved over the PWS lesion in a back and forth motion so that each area of the PWS is passed 2–3 times. The chilled plate must remain in contact with the skin at all times or epidermal thermal injury can occur, increasing the risk of side effects including dyspigmentation and scarring.

Patients describe only mild discomfort, less than that associated with the traditional FLPDL. Postoperatively, patients often experience mild to moderate oedema, which can be treated with elevation of the affected body parts and ice packs. There is no post-treatment purpura and generally no crusting. If small blisters occur, usually because the chilled plate was not kept in close contact with the skin, patients can be treated with topical antibiotics. Once again, post-treatment sun avoidance is important to prevent hyperpigmentation.

We would not recommend the KTP laser as the first-line treatment of PWS birthmarks. However, for patients not achieving the desired degree of PWS blanching after multiple treatments with the FLPDL or for very sensitive areas such as the hand, the KTP laser offers another treatment option.

INTENSE PULSED LIGHT SOURCE

Sharplan-ESC Medical Systems Ltd (Yokneam, Israel) offers an intense pulsed light source (IPLS) as an alternative method for treating vascular lesions. A high-energy flashlamp emits non-coherent light (515–1200 nm) utilising cut-off filters (515, 550, 570 or 590 nm) to eliminate shorter wavelengths. Fluences of 3–90 J/cm^2 can be delivered by single, double or triple pulse sequences with pulse durations of 0.5–25 ms and a delay between pulses of 1–300 ms. A large 8 × 35 mm (2.8 cm^2) spot size allows rapid treatment and promotes deeper penetration of higher fluences as a result of less optical scattering. A cooled water-based gel is placed between the skin and the emitting crystal to protect the epidermis.

It has been suggested that non-coherent light will allow thermocoagulation of a wide range of vessel sizes and depths [29]. By utilising either long pulses or multiple-pulse sequences and splitting up higher energy densities, the IPLS may heat deeper into vessels and allow the treatment of larger blood vessels difficult to coagulate with the 585 nm 450 μs FLPDL. In addition, the longer wavelengths should allow destruction of vessels deeper in the dermis. A recent study by Raulin et al. [30] on 37 patients achieved complete clearing in 25% and good clearing (70–99%) in 50% of previously untreated PWS birthmarks. Of 13 PWS previously treated with lasers, 8% (one predominantly red lesion) was completely cleared and 50% (two red and four purple lesions) improved to good clearing. All patients experienced immediate post-treatment erythema and 76% developed purpura. The purpura most often resolved in 24–72 h, but in a few patients persisted for a maximum of 7 days. Crusting was noted in 20% of patients and hypopigmentation and hyperpigmentation were reported in 8.1% and 2.7% of patients, respectively. Scarring did not occur. The authors indicated that with further refinement the IPLS technique might be useful for the primary or adjunctive treatment of PWS, especially dark hypertrophic lesions.

We do not have personal experience with the IPLS system but agree that additional research is required to optimise this system and determine its potential for PWS treatment.

CONCLUSION

Lasers are the modality of choice for the treatment of PWS birthmarks. The clinician now has several lasers available to achieve optimal results. Different PWS lesions respond best to different wavelengths and pulse durations. Sometimes improved results can be obtained by combining a variety of different lasers as each has a unique depth of penetration and thus, may ablate different ectatic vessels within the PWS.

Most patients still do not achieve complete resolution of their PWS. This remains a challenge for the future. Higher fluences will be required to achieve better vessel destruction. The epidermal protection offered by CSC or the chilled sapphire plate is the first step towards achieving better PWS blanching. Ongoing studies will explore the maximum fluence that can be delivered in conjunction with these cooling modalities.

Another promising lead is optimisation of laser treatment parameters based on the unique characteristics of each PWS. We are currently working on methods to image and determine the depth and size of PWS blood vessels on an individual patient basis [31]. This information combined with a measurement of the patient's epidermal melanin concentration could be used to tailor treatment parameters, with the expectation of complete PWS blanching in the majority of patients.

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