

KTP Laser Treatment of Port Wine Stains and Telangiectasia: Brief Summary of Findings

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Port Wine Stains and Telangiectasia

Microvascular malformations such as port wine stains (PWS) and telangiectases are a treatment challenge, and a disfiguring burden for many patients. PWS occur in up to 0.5 percent of newborns as a congenital malformation of

dermal venules. In infancy, the abnormal vessels are small, and most childhood PWS are pink or red, flat lesions. Over time, the venules dilate and the PWS becomes progressively darker and raised, frequently leading to hypertrophic, massive lesions in adulthood. Most telangiectases are comparatively large vessels, ranging from 150 μm to 1 mm in diameter.

Following the theory of “selective photothermolysis” developed in this laboratory, pulsed lasers were specifically designed during the 1980’s for treatment of pediatric PWS. Pulsed dye lasers at 577–600 nm cause selective microvascular damage, and have proven to be safe and usually effective for pediatric PWS. However, pulsed dye laser treatment usually requires a series of many treatments, and is often only partially effective. Gross purpura occurs after each treatment, posing a further cosmetic problem for patients. Clinically, pulsed dye lasers appear to work better for pediatric PWS than for adult PWS – presumably because of the change in vessel size and depth with aging.

Selective Photothermolysis and Laser Pulse Duration

Selective photothermolysis begins with local absorption with light energy, in target chromophores such as hemoglobins in blood vessels, or melanin in pigmented lesions. During the laser pulse, the target temperature increases, and a competition arises between active



Port Wine Stain on back of female patient: Pre-treatment



Port Wine Stain: Substantial clearing after a single treatment

heating and passive cooling of the targets by heat conduction. The “thermal relaxation time” is defined as the time necessary for significant cooling of a given target structure, and depends upon the target size and shape. For maximum efficiency and selectivity, the laser pulse duration should be approximately equal to or less than the thermal relaxation time. However, short laser pulses tend to cause violent mechanical effects such as vessel rupture; therefore, the ideal pulse duration appears to be essentially equal to thermal relaxation time.

It has been known for years that pulsed dye lasers fall short of the ideal pulsewidths for treating most PWS and telangiectases, which lie in the 1–30 ms region, depending on the vessel size. Clinically, the larger and deeper vessels of adult PWS and many telangiectases appear to be “out of reach” for the wavelengths and pulsewidths currently available with pulsed dye lasers. Recently, a 1.5 ms pulsed dye laser with output at 590–600 nm has become available, which may partially solve the problem. However, many PWS and telangiectases extend anatomically beyond the effective depth for treatment. A mechanism which creates deep yet selective injury to larger vessels is clearly needed.

The 50 μm diameter vessels of an infant’s pink port wine stain have a typical thermal relaxation time of about 1 millisecond (ms). However, the thermal relaxation time increases dramatically for larger vessels. A 150 μm adult PWS vessel has a thermal relaxation time of about 10 ms, and a 500 μm telangiectasia has a thermal relaxation time of about 100 ms. Individual PWS often have many different vessel sizes present, with thermal relaxation times ranging over 2 orders of magnitude; a single laser duration cannot achieve optimal efficacy for all lesions.

Another consideration in favor of using somewhat longer pulses is that the abnormal vessels tend to be larger than normal ones. When the pulse duration exceeds the thermal relaxation time of a small vessel, that vessel tends to escape damage relative to the larger vessels. This may be a factor increasing the purpura and healing time after pulsed dye laser treatments of PWS. Pulses longer than about 3 ms tend to spare normal capillaries and venules, at the same fluences with damage larger, ectatic vessels of PWS or telangiectases. Unfortunately, pulsed dye lasers do not like to produce pulses much longer than 1 ms, and continuous-wave lasers such as argon, argon-dye, and krypton lasers do not provide enough power for useful exposure durations below about 30 ms, even with mechanical scanners.



Pre-treatment Telangiectasia: Regions 7, 8 and 9



Telangiectasia: Region 7, 4 month follow-up

The ideal laser would provide a variable pulse duration over the wide region of interest. Unlike dye lasers or continuous-wave lasers with scanners, the KTP laser is capable of being pulsed from 1 to 30 milliseconds with sufficient energy for treating microvascular lesions. Its 532 nm wavelength has approximately equal and selective absorption in blood vessels, compared with conventional 585 nm pulsed dye lasers. We therefore, performed animal studies with this laser, followed by a pilot clinical study in adults with PWS.

Summary of KTP Laser Studies

Albino rabbit ear venules ranging from about 100–400 μm diameter were used as an in-vivo model of telangiectasia. The Orion KTP laser (Laserscope) was operated at pulse durations of 1–30 ms, with exposure diameter of 1 mm, over a range of fluences up to 50 J/cm². Side-by-side comparison was made with a standard clinical pulsed dye laser (Candela) operating at 585 nm, 0.4 ms pulses. Gross responses, histopathology of biopsies taken immediately after exposures, and healing were observed.



Telangiectasia: Region 8, 4 month follow-up



Telangiectasia: Region 9, 4 month follow-up

The dye laser produced immediate purpura and hemorrhage at all fluences greater than 4 J/cm² (treatment fluence range), in all vessel sizes. Increasing the pulsed dye laser fluence produced greater hemorrhage and purpura. In contrast, KTP laser exposures caused immediate vessel coagulation at similar fluences to the dye laser, but without hemorrhage or purpura. At higher KTP laser fluences, there was immediate vessel disappearance. The “disappeared” portion of a venule was centered at the site of KTP laser exposure, but extended 1–3 mm beyond the border of the KTP laser exposure site. For KTP laser fluences above the threshold for vessel disappearance, there was not apparently greater injury. When the KTP laser pulse duration exceeded the thermal relaxation time for a given vessel diameter, the threshold for damage increased in accordance with theory. Healing occurred without scarring after both pulsed dye and KTP laser. Delayed purpura was more impressive with the pulsed dye laser, but was not specifically measured.

Histologically, after pulsed dye laser there was an intravascular thermal coagulum, moderate thermal damage to the vessel wall, and hemorrhage secondary to tears in the vessel wall. After KTP laser exposures at comparable fluence, there was comparable vessel wall injury, without hemorrhage. Immediate vessel “disappearance” at higher KTP laser fluences correlated histologically to entirely empty thermally damaged vessels.

An immediate physical phenomenon must be invoked to explain clearing of the intravascular lumen, and vessel “disappearance” after KTP laser pulses. Active or passive vasoconstriction cannot explain complete gross disappearance, nor emptying of the vessel lumen. We, therefore, propose the mechanism of gentle intravascular cavitation (vaporization) to explain these results. Rupture of vessels from pulsed dye laser exposure is known to be caused by violent vaporization of blood within the vessel, occurring at about 140° C. With the longer KTP laser pulses, expansion of the intravascular steam bubble during the laser pulse is less violent, and clearly does not rupture the vessel wall. The steam bubble is allowed to expand along the axis of the vessel, clearing the lumen and pushing a column of hot blood along the vessel the lumen. As the vessel cools during its thermal relaxation time, the vapor bubble condenses, collapsing the vessel wall. Thermal coagulation of the blood, now ejected well beyond the actual exposure site, creates an intravascular “plug,” leaving an empty, thermally damaged lumen at and around the site of KTP laser exposure. Since gentle intravascular vaporization forces extremely hot blood to travel millimeters beyond the actual site of laser impact, this mechanism can potentially cause thermal damage to vessels far beyond the actual penetration depth of a given wavelength.

Clinical Study Summary

The animal study data were used to define parameters for treatment of PWS, and a clinical study was performed with the KTP laser at different pulse durations, for treatment of adult port wine stains on the extremities, trunk and face. A total of 11 points were included, with PWS ranging from pink to purple in color.

KTP laser exposures were given initially in 12 test sites on each patient, delivered at three fluences for each of four different pulse durations. Immediate response was a transient blanching reaction without purpura, in contrast to pulsed dye laser-induced immediate purpura. Delayed purpura developed in the KTP laser exposure sites within

several days, and resolved in approximately 10–14 days. Evaluation of PWS lightening in the test sites was used to choose the KTP laser parameters for treatment of the remaining PWS. Despite the small number of patients in this study, there was an apparent trend for those with purple PWS to respond best to 5 ms pulses, and those with red PWS to respond best to 3 ms pulses. Each patient received a single treatment session.

At four weeks after treatment, the degree of PWS lightening was assessed by a skin reflectometer, and by an independent group of observers using a visual analog scale to grade randomized clinical photographs. All 11 patients had significant lightening of PWS after a single KTP laser treatment. None of the patients had scarring or textural changes; hypopigmentation similar to that seen with pulsed dye laser treatment of PWS was noted. There was a correlation between color of the PWS and success of treatment, with darker PWS showing generally better response. For dark purple PWS, 75 percent lightening was typical, in contrast to 25–50 percent lightening of pink and red PWS.



A. Front part of Port Wine Stain cleared up substantially with single treatment.

B. Port Wine Stain on neck of patient with substantial clearing in the hexagonal test site.

Discussion

This work shows that the KTP laser is particularly useful for treating adult PWS and telangiectases. KTP laser pulses in the 3–10 ms region cause selective microvascular damage with substantially less purpura and hemorrhage than the standard 0.4 ms, 585 nm pulsed dye lasers used for PWS treatment. The KTP laser pulse duration range is theoretically ideal for treating most adult PWS and telangiectasia, whereas pulsed dye lasers are well suited for treating the smaller-diameter vessels of pediatric PWS. Our animal and clinical results with the KTP laser are consistent with this theory. The KTP laser is effective for treatment of adult PWS, and appears to be more effective with darker PWS lesions in a single treatment. These conclusions are based on the limited number of 11 patients.

At treatment fluences, there is a qualitative difference in the mechanism of action for the KTP laser compared with either pulsed dye or continuous-wave lasers. The KTP laser causes gentle intravascular vaporization, which clears the vessel lumen of blood at the site of laser exposure, and extends thermal injury of the vessel well beyond the actual exposure site. To our knowledge, this mechanism has not been previously studied. Given the vertical architecture of PWS and some telangiectases, gentle intravascular vaporization may improve efficacy by extending the region of selective vascular injury deeper than the penetration depth of 532 nm light.

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