The use of lasers in dermatology

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There are now a range of lasers capable of effective treatment of vascular, pigmented and other skin lesions with a high degree of selectivity. Understanding the complex interactions between laser irradiation and often diverse lesion morphology is the key to determining the appropriateness of treatment.

Laser (light amplification by stimulated emission of radiation) devices generate coherent light, often within a single band or just a few narrow wavelength bands (monochromatic light). The properties that make lasers useful in dermatology are their ability to focus high-energy light on to the skin, either directly or via optical fibres, in a way that permits accurate control of energy (fluence) and exposure time (pulse width). Because smaller structures when heated by laser light lose heat more rapidly than larger structures, manipulation of pulse width can be used to confine thermal injury to target structures of variable sizes. In addition, the light-absorption characteristics of target structures can be exploited by choosing a wavelength of laser light that is preferentially absorbed by them to cause selective injury. These principles form the basis of the theory of selective photothermolysis (Anderson and Parrish, 1981).

The earliest work with lasers in dermatology was largely a result of recognizing the potential of existing technology (Goldman and Richfield, 1964). However, in recent years, dermatological lasers have been developed for specific applications. The resultant proliferation of new laser technology has often outpaced our ability to effectively evaluate it.

The major dermatological laser applications are perhaps most conveniently considered in relation to the primary target (chromophore). Haemoglobin frequently offers an excellent target for a large array of vascular lesions. Melanin is the primary target for a number of pigmented lesions and hair follicles, whereas a wide range of exogenous pigments can be targeted in tattoos. The use of water as a target offers the opportunity to ablate a large range of lesions that have no specific chromophore.

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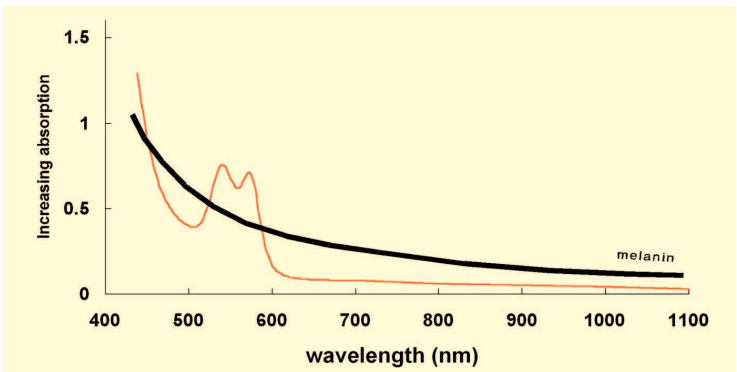

Figure 1. Relative absorption spectra for melanin and oxyhaemoglobin.

VASCULAR LESIONS

All vascular lasers take advantage of the relatively greater absorption of haemoglobin compared with melanin (the other major cutaneous chromophore in the visible spectrum) (*Figure 1*). This difference is greatest between the two major absorption peaks of haemoglobin (540–577 nm).

Although early studies demonstrated significant benefits in a variety of vascular lesions using the argon laser (488/514 nm) (Apfelberg et al, 1981), the relatively high absorption by melanin at these wavelengths has meant that it has been superseded by more effective and safer devices. Of these, the pulsed-dye lasers (577–600 nm) and potassium titanyl phosphate (KTP) lasers (532 nm) have become most popular, although other devices are available (argon-dye, krypton, copper vapour/bromide).

Of the many vascular lesions treated with lasers, port wine stains (PWS) and various forms of telangiectasia are the most numerous.

PORT WINE STAIN MALFORMATIONS

Pulsed-dye lasers (PDL) have become established as the treatment of choice for the majority of

PWS malformations (Garden et al, 1988). Although early lasers employed the more haemoglobin-selective 577 nm wavelength, most PDL now use 585 nm. The lower absorption by haemoglobin at this wavelength permits greater depth of penetration in the skin, which compensates for a relative reduction in vascular selectivity (Hayashi et al, 1988; Tan et al, 1990). Although the almost invariable post-treatment purpura and inflammatory reactions are troublesome in the short term, improvements in the region of 75% in the majority treated and an exceptionally low risk of adverse effects (Seukeran et al, 1997) strongly favour their use, particularly in children, where other lasers in the past were typically less effective and more hazardous. However, treatment responses are variable and complete clearance rarely occurs (*Figure 2*). As a result, alternative treatments have been explored.

A small proportion of PWS malformations seem to show benefit from KTP lasers, particularly in older patients with more raised or nodular lesions. Newer PDL with longer pulse widths and wavelengths in the 595–600 nm range designed to address the problem of leg telangiectasia have recently been applied to PWS malformations (Edstrom and Ros, 1997). Although there is currently a paucity of good evidence to support routine use of these lasers, early reports suggest potential advantages over conventional 585 nm PDL in some PWS malformations, particularly where resistant or in older patients.

Presumed benefits from greater depth of penetration at these wavelengths are offset by even further reduction in vascular selectivity. The latter necessitates higher fluences and a requirement to protect the melanin-containing epidermis to avoid adverse treatment reactions. Protection of the epidermis can generally be achieved by a process termed dynamic cooling, in which a controlled spray of a volatile liquid coolant (tetrafluoroethane) is allowed to evaporate briefly before the laser impact. The resultant cooling is spatially confined to the epidermis, leaving the dermal vasculature unaffected and therefore susceptible to the full effect of the laser-induced thermal injury (Nelson et al, 1996).

OTHER VASCULAR LESIONS

Numerous acquired and naevoid vascular lesions can be improved with laser treatment. The shorter pulse widths and longer wavelengths available with PDL favour their use for smaller and more deeply situated vessels, as are often encountered in capillary haemangiomas (strawberry naevi). While early treatment of capillary haemangiomas has been advocated in an attempt to prevent the troublesome extensive proliferation that occurs in a minority, available evidence suggests that, in the majority, moderate changes in colour and size are often all that can be achieved in established lesions, even after multiple treatments. The value of treatment in asymptomatic lesions is in doubt, but ulcerated lesions can often be symptomatically improved (Morelli et al, 1991), and lesions in potentially problematic areas, such as perorbital and perioral regions, may merit treatment in the hope of minimizing problems in the early part of childhood.

While fine telangiectasia are perhaps more effectively treated with PDL (577–585 nm), larger superficial telangiectasia — as seen in association with rosacea and photoaging — are often more responsive to longer pulse width lasers such as the KTP laser. This laser has relatively poor dermal penetration compared with the PDL, but this is of little importance in superficial lesions, and the lack of post-treatment purpura is welcomed by patients (West and Alster, 1998).

Larger and more deeply situated vessels present more of a problem, requiring both deeper penetration and longer pulse widths for efficient vessel destruction. A number of lasers emitting at longer wavelengths — ranging from 595–600 nm PDL, 750 nm alexandrite lasers, 800 nm diode lasers to 1064 nm neodymium:yttrium-aluminium-garnet (Nd:YAG) lasers — have been developed to deal primarily with leg telangiectasia. Depth of penetration at these wavelengths is always at the expense of low vascular selectivity, and surface cooling is invariably required. This can be

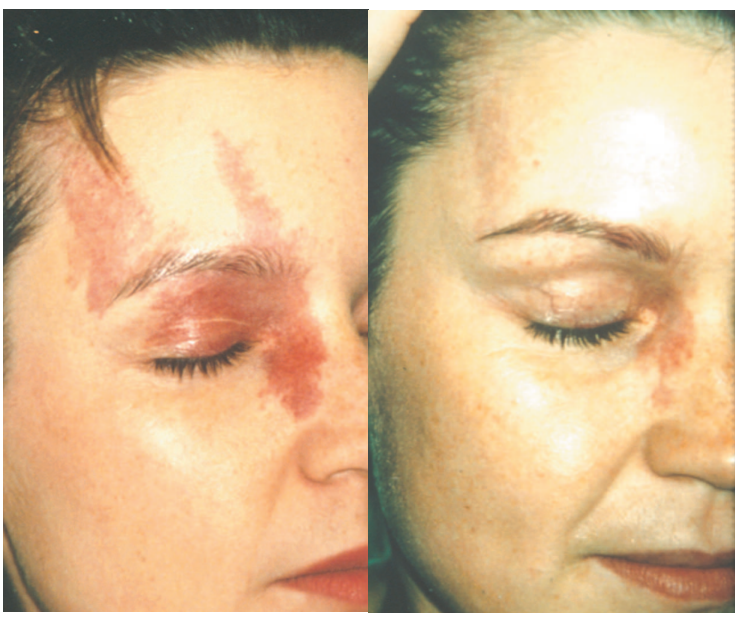

Figure 2. PWS malformation before and good but incomplete response after eight treatments with a pulsed-dye laser (585 nm).

achieved by dynamic cooling as described above, or contact cooling with a range of techniques, the most popular being delivery of the laser light through a chilled sapphire window. An alternative approach for managing deeper lesions, particularly deep venous malformations, is interstitial laser treatment — in which fine optical fibres are inserted through cannulae to enable usually Nd:YAG-laser irradiation of deeply situated structures while avoiding injury to the epidermis and superficial dermis (Achauer et al, 1998).

PIGMENTED LESIONS

The broad range of wavelengths of light absorbed by melanin are such that lasers emitting across the visible spectrum can be used to treat melanocytic lesions. When individual melanocytes are targeted, Q-switched lasers with nanosecond duration pulse widths can be used to target individual melanosomes. The resultant effect is probably more photomechanical than photothermal, producing melanocyte cell death.

Lasers such as the Q-switched ruby (694 nm) and Q-switched alexandrite (755 nm) can produce good improvements in naevus of Ota, lentigines and many café-au-lait patches, among other less common lesions (Geronemus, 1992; Kilmer et al, 1994; Alster and Williams, 1995). The shorter wavelength of the frequency-doubled Q-switched Nd:YAG (532 nm) does not penetrate sufficiently to influence deeper lesions such as naevus of Ota, whereas with the more deeply penetrating 1064 nm wavelength, good responses are seen (*Figure 3*). Disappointing results with other pigmented lesions such as melasma and post-inflammatory hyperpigmentation probably reflect the nature of repair mechanisms which feature further post-inflammatory hyperpigmentation rather than the efficacy of these lasers in destroying pigment-containing cells.

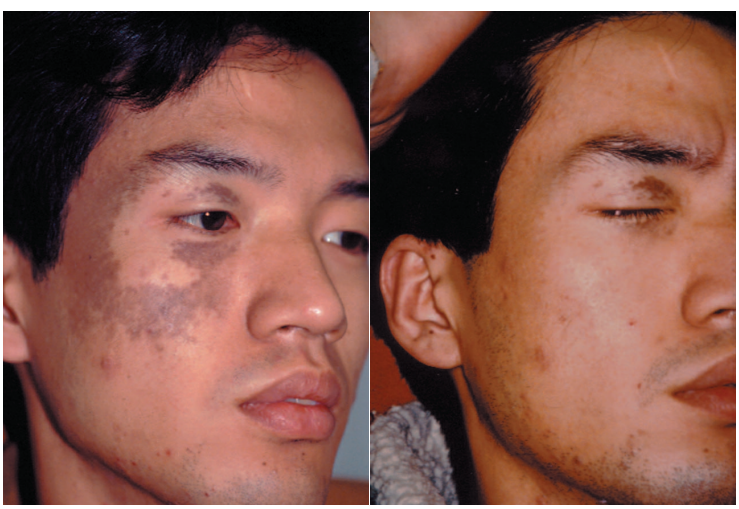

Figure 3. Naevus of Ota before and after three treatments with a Q-switched neodymium:yttrium-aluminium-garnet (Nd:YAG) laser (1064 nm) (upper eyelid untreated).

The small size of intracellular pigment in tattoos lends itself to treatment with this group of lasers, and very good responses are often achieved after multiple treatments. Although black or dark blue pigments generally respond well, the vast range of tattoo pigments used make prediction of response difficult in individual cases, and many brighter colours do not fully fade with any available lasers.

Where target structures have variable pigment distribution within the lesion, as is often the case with congenital melanocytic naevi, treatment with nanosecond-pulsed Q-switched lasers results in partial lesion destruction (Grevelink et al, 1997), and often disappointing clinical results. Longer pulse width lasers, such as the normal-mode ruby laser (1–5 ms), permit thermal diffusion away from the target pigment to produce a less specific damage. These lasers, in effect, use the melanised cells within the lesion as a surrogate target to produce more widespread injury to adjacent non-melanised structures, and improve responses in this type of lesion (Ueda and Imayama, 1997).

LASER HAIR REMOVAL

Using a similar principle, an increasing number of lasers with millisecond pulse widths have been developed in an attempt to induce both temporary and permanent injury to hair follicles. The presumed targets are the stem cells thought to be situated in the hair bulge at the level of the insertion of erector pili, and the dermal papilla.

The normal-mode ruby laser, long-pulse alexandrite (3–40 ms pulse width) and more recently diode lasers (800 nm) and long-pulse Nd:YAG 1064 nm lasers (10–150 ms pulse widths) have all been investigated. The overlying melanin-containing epidermis presents a significant competing chromophore, particularly in darker skin types. It has been postulated that more selective injury to the larger sized hair follicle over the smaller sized epidermis might be achievable by using longer pulse widths. However, significant advantages of this approach have yet to be demonstrated. Epidermal cooling probably offers more significant advantages in terms of epidermal protection.

All the lasers mentioned have been shown to induce temporary hair-growth delay. Good clinical evidence of longer-term efficacy (12 months or more) is limited to facial hair with the normal-mode ruby laser (Sommer et al, 1999) and bikini line hair with the long-pulsed alexandrite laser (Lloyd and Mirkov, 2000). Whether this represents permanent improvement, or can be extrapolated to other sites, remains unknown.

LASER ABLATION

Ablation of skin where no specific chromophore is present can be achieved by lasers where water is the major target. The carbon-dioxide laser (10 600 nm) and more recently the erbium (Er:YAG) laser (2940 nm), when used with pulse widths of less than 1 ms, can produce very localized ablation of skin through vaporization. The selectivity of skin ablation in these circumstances depends on direct vision or knowledge of likely required ablation depth by the operator.

A range of skin lesions, including epidermal naevi, trichoepitheliomata, syringomata and angiofibromas of epiloia, can be ablated in this way, leaving significantly less damage to non-target structures and improving healing compared with other treatment modalities.

These lasers have found widespread use in the treatment of skin irregularity, as seen in skin photoaging and superficial forms of scarring. Controlled ablation of altered epidermis and superficial dermis is followed by healing with superficial scarring, which often improves the skin's appearance. The degree of improvement correlates with the depth of ablation, and in part with the degree of thermal injury. The latter is more marked with the carbon-dioxide laser than with the Er:YAG laser, although the latter can be configured to produce similar levels of thermal injury. Greater thermal injury improves visibility at greater ablation depths by coagulating smaller vessels and reducing bleeding, but is associated with more prolonged wound healing and persistent redness. Although texture improvements are greater with deeper treatments, adverse effects such as hypopigmentation and colour and/or texture mismatch with surrounding untreated skin are more frequent (Khatri et al, 1999).

A more recent approach to photoaging has been to attempt to induce thermal injury to the superficial dermis while protecting the epidermis by cooling devices. The rationale is to induce non-ablative dermal remodelling. Early work has shown identifiable histological effects, but less than convincing clinical benefit.

CONCLUSIONS

An increasing number of dermatological conditions can be improved by laser treatment, but not all new devices have been adequately demonstrated to produce significant advantages over existing technology. Alternative devices such as non-laser filtered light sources have been reported to produce similar benefits to some lasers in certain cases, but these devices also need more in-depth evaluation. Laser developments in dermatology seem to be increasing at a rapid pace. Achieving an understanding of laser interactions with the skin and benefits of treatment that keep pace with the technology will be the major challenge for the future. HM

Conflict of interest: none.

Achauer BM, Celikoz B, VanderKam VM (1998) Intralesional bare fiber laser treatment of hemangioma of infancy. *Plast Reconstr Surg* **101:** 1212–7

Alster TS, Williams CM (1995) Treatment of naevus of Ota by the Q-switched alexandrite laser. *Dermatol Surg* **21:** 592–6

Anderson RR, Parrish JA (1981) Microvasculature can be selectively damaged using dye lasers: basic theory and experimental evidence in human skin. *Lasers Surg Med* **1:** 263–76

Apfelberg DB, Maser MR, Lash H, Rivers J (1981) The argon laser for cutaneous lesions. *JAMA* **245**: 2073–5

Edstrom DW, Ros AM (1997) The treatment of port-wine stains with the pulsed dye laser at 600 nm. *Br J Dermatol* **136:** 360–3

Garden JM, Polla LL, Tan OT (1988) The treatment of port-wine stains by the pulsed dye laser. *Arch Dermatol* **124**: 889–96

Geronemus RG (1992) Q-Switched Ruby Laser Therapy of Nevus of Ota. *Arch Dermatol* **128**: 1618–22

Goldman L, Richfield D (1964) The effect of repeated exposures to laser beams. *Acta Derm Venereol* **44**: 264

Grevelink JM, van Leeuwen RL, Anderson RR, Byers HR (1997) Clinical and histological responses of congenital melanocytic nevi after single treatment with Q-switched lasers. *Arch Dermatol* **133(3):** 349–53

Hayashi H, Yasuda Y, Tsukada S (1988) Flashlamp dye laser treatment of port-wine stains: the comparative effects of SPTL1-P (577nm) and SPTL-1 (585nm). *J Japan Soc Laser Med* **9:** 459–62

Khatri KA, Ross V, Grevelink JM, Magro CM, Anderson RR (1999) Comparison of erbium:YAG and carbon dioxide lasers in resurfacing of facial rhytides. *Arch Dermatol* **135(4):** 391–7

Kilmer SL, Wheeland RG, Goldberg DJ, Anderson RR (1994) Treatment of epidermal pigmented lesions with the frequency-doubled Q-switched Nd:YAG Laser: A controlled, single-impact, dose-response, multicenter trial. *Arch Dermatol* **130:** 1515–9

Lloyd JR, Mirkov M (2000) Long-term evaluation of the long-pulsed alexandrite laser for the removal of bikini hair at shortened treatment intervals. *Dermatol Surg* **26(7)**: 633–7

Morelli JG, Tan OT, Weston WL (1991) Treatment of ulcerated hemangiomas with the pulsed tunable dye laser. *Am J Dis Child* **145:** 1062–4

Nelson JS, Milner TE, Anvari B, Tanenbaum S, Svaasand LO, Kimel S (1996) Dynamic epidermal cooling in conjunction with laser-induced photothermolysis of port wine stain blood vessels. *Lasers Surg Med* **19(2)**: 224–9

Seukeran DC, Collins P, Sheehan-Dare RA (1997) Adverse reactions following pulsed tunable dye laser treatment of port wine stains in 701 patients. *Br J Dermatol* **136**: 725–9

Sommer S, Render C, Sheehan-Dare R (1999) Facial hirsutism treated with the normal-mode ruby laser: results of a 12-month follow-up study. *J Am Acad Dermatol* **41(6)**: 974–9

Tan OT, Morrison P, Kurban AK (1990) 585-nm for the treatment of Port-Wine stains. *Plast Reconstr Surg* **86:** 1112–7

Ueda S, Imayama S (1997) Normal-mode ruby laser for treating congenital nevi. *Arch Dermatol* **133(3):** 355–9

West TB, Alster TS (1998) Comparison of the long-pulse dye (590-595 nm) and KTP (532 nm) lasers in the treatment of facial and leg telangiectasias. *Dermatol Surg* **24:** 221–6

KEY POINTS

- Selective damage to skin targets can be achieved by choosing appropriate laser variables.
- The wavelength of the laser can be chosen to selectively target skin chromophores depending on their absorption characteristics.
- The exposure time (pulse width) can be chosen to confine damage to skin structures, larger structures requiring a longer pulse width.
- Epidermal cooling can reduce unwanted damage when treating dermal structures.