Abstract. Very shortly after the laser's first successful firing in 1960, applications were found in the medical field in the specialities of ophthalmology and dermatology and have since expanded to include indications in plastic and reconstructive surgery. In the photodestructive mode, laser energy is used selectively to vaporize, incise, excise, ablate and coagulate target tissue; the surgical laser can also degrade or denature protein in the target tissue, and the latter photoreaction now forms the basis for laser tissue welding in a variety of tissue types. The author refers to these photodestructive applications as high reactive-level laser treatment, or HLLT. In laser therapeutic applications, the temperature of the cells may rise only very slightly or not at all, and there is no immediate irreversible change in the target tissue architecture. The level of reaction is thus lower than the cell survival threshold, giving a direct photoactivative effect. The author refers to this as low reactive-level laser therapy, or LLLT: LLLT applications include pain attenuation, wound healing acceleration; enhanced remodeling in accelerated bone and tendon repair; restoration of normal neural function; normalization of abnormal hormonal function; modulation of the autoimmune system; control of hyper- and hypotension and so on. HLLT and LLLT are contrasted and compared, and applications of both HLLT and LLLT in PRS are discussed in brief. (Keio J Med 42 (4): 191-195, December 1993)

Key words: laser surgery, laser therapy, simultaneous LLLT, pure LLLT

Introduction

When Theodore Maiman successfully fired the first ruby laser in 1960, scientists were presented with a new, unique light source, much more powerful than anything that had existed before. First ophthalmologic, and then dermatological applications were quickly developed. The pigment-dependent absorption of the laser beam in abnormally coloured cells or materials was the basis for these applications. From these early beginnings, more applications have been found having particular advantages which are connected with the physical characteristics of the laser, compared with the existing conventional methodologies.

Radiant heat and conducted heat

Surgical laser generally depend on creating a thermal response in the target tissue. Both the degree and type of heat generated determine the ultimate bioreaction. The combination of a high absorption rate in the target tissue and ultrashort beam exposure times of microseconds or less gives an almost instantaneous transfer of light to heat, limited to the target abnormal tissue or cells. This is referred to as the radiant heat effect, and is capable of very high cell-selective treatment with relatively little damage to surrounding normal cells. If the absorption rate is high, but the exposure time is longer, in the region of tens or hundreds of milliseconds up to seconds, then a secondary thermal wave is transferred from the target tissue to the surrounding normal tissues in the form of conducted heat, and some damage will result in these surrounding tissues. This is the conducted heat effect, and is only comparatively cell-selective. Both have applications in laser treatment.

High reactive-level laser treatment: HLLT

A range of photothermally destructive bioreactions is possible, from total vaporization and carbonization to tissue protein degradation and denaturation (Fig 1). These reactions depend on both the absorption rate of the tissue, determined by the wavelength of the laser beam, and the power and energy densities of the incident
192 Ohshiro T and Fujino T: Laser Applications in PRS

Fig 1 Temperature ranges and types of photothermal and non-photothermal bioreactions.

Fig 2 Schematic representation of a 2 W laser beam focused by a lens, with the power densities given at various spot diameters. The power density varies as an inverse square of the irradiated spot diameter.

beam. In the surgical laser, the power density is the ultimate determinant of the laser-tissue reaction. Figure 2 schematically shows a 2 W laser beam passing through a focusing lens, and the power densities at different points of the beam (the power density or PD is derived from the incident power in watts divided by the irradiated area in square centimetres, expressed in watts per square centimetre, W/cm²); dramatic differences exist between the power density at the focal waist (just over 25,000 W/cm²) and at a diameter 10 times the waist diameter (255 W/cm²). The flexibility of control from incision and vaporization to haemostasis was one of the factors which set the surgical laser above its conventional predecessors. All of these reactions represent some form of irreversible photodestructive change to the cell architecture, so the level of reaction can be regarded as being higher than the survival threshold of the targeted cells. The author collectively refers to the photosurgical effects of the laser as high reactive-level laser treatment, or HLLT. HLLT is used in PRS for the excision of keloids and large hypertrophic scars; incision and excision of tissue where there is a high level of possible blood loss, such as large cavernous haemangioma; selective removal of skin lesions; laser debridement; laser peeling, and so on.

HLLT systems can be used singly, in combination with other laser systems or in combination with conventional surgical and medical methods.

**Simultaneous LLLT**

Early clinicians and researchers working with HLLT reported that patients experienced some unexpected but beneficial side effects after undergoing a laser surgical procedure, compared to the same procedure carried out by conventional methods. Such side effects included amongst others less postoperative pain, less oedema and better initial wound healing. This has been referred to by some authors as the α effect. Figure 3 represents an impact of a surgical laser beam on tissue. Many surgical beams have a Gaussian distribution, represented by the bell-like curve seen in the upper portion of the figure, with the greatest power found at the peak of the curve, gradually diminishing towards the periphery. A range of roughly concentric bioreactions will thus occur simul-
taneously at the surface of the target tissue, with the most heat (i.e. the most destructive level of reaction) being generated at the centre. At the same time, the beam penetrates into the tissue at the speed of light, creating a similar series of 3-dimensional areas of varying but simultaneously-occurring bioreactions with very low power densities at the periphery of the beam. The author has proposed that the low levels of light energy are directly absorbed by the cells at a subcellular level. This alters the energy level of the cell, changing its metabolism and modulating the function of the cellular components, and ultimately the cell itself. That could very plausibly explain the α effect, and the author refers to this as simultaneous low-reactivel level laser therapy, (simultaneous LLLT).

**Pure LLLT, and the terminology**

The pioneering work of the late Endre Mester into specific therapeutic applications is well-recognized in the literature. Various criteria have been advanced for classifying a pure LLLT beam, but the vast majority of the terminology is either system-based or marketing-driven, and should thus be discarded. The term “LLLT” has now become internationally accepted to cover the clinical aspects of this type of application, and “photobiomodulation” or “photobioactivation” have been suggested as the best terms to use when talking about the basic reactions at a cellular or subcellular level, such as in experimental work.

The applications of LLLT continue to expand, as basic research elucidates the underlying mechanisms empirically reported by clinicians, thereby increasing medico-scientific acceptance of LLLT as a legitimate medical tool. Reported applications of LLLT in PRS include: Postoperative pain control; almost immediate improvement of impaired local microcirculation and a secondary effect on systemic circulation, useful for revitalizing vasculary-impaired grafts and flaps; resorption of potentially-damaging haematomata in skin grafts; applications in hyper- and hypopigmented skin lesions; control of postoperative secondary hyperpigmentation; control of hypertrophic scarring and keloids, and so on. LLLT is also used as a complementary tool with HLLT systems, conventional conservative and nonconservative techniques, or in a combination of any or all of the above.

**Clinical Applications**

The majority of naevi consist of some form of abnormal colouration of the skin, with or without some configurational abnormality. Naevi can be generally subdivided into two main groups: The blood vessel anomaly group (BVAG), and the melanin anomaly group (MAG). Table 1 below summarizes the main naevus types, classified by the author for laser treatment.

**Blood vessel anomaly group**

In the blood vessel anomaly group the abnormal colour comes from the erythrocytes or red blood cells in ectatic or overabundant blood vessels. Because of the blood flow factor, this group is classified as the moving pigment group. Laser treatment must therefore act rapidly in order to achieve a successful effect, because of the cooling effect of the blood flow. The high peak powers (MW) and ultrashort acting time (microsecond or nanosecond pulse widths) of pulsed dye and Q-switched pulsed ruby lasers produce a highly cell-selective instantaneous radiant heat effect in the target vessels, limiting pigment-selective coagulative damage to the targeted cells, but because of the high radiant heat effect, selectively coagulating the blood vessels despite the flow of blood. Slower-acting continuous wave lasers can still achieve some degree of cell-selectivity, but the cooling effect of the blood flow lowers the effectiveness in this group, and there is a spread of secondary thermal damage caused by the conducted heat effect.

**Table 1 Ohshiro’s Classification of Naevi**

<table>
<thead>
<tr>
<th>Naevi Group</th>
<th>Examples</th>
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<tbody>
<tr>
<td>Static Group: naevus cell naevus, hairy pigmented naevus, naevus spilus, Becker’s naevus, Ota’s naevus, cafe au lait spots of von Recklinghausen’s disease, miliary spots of skin and mucosa in Peutz-Jeghers syndrome, chloasma, ephelides, lentigo, vitilgo, naevus depigmentosus, xanthoma, tattoo, etcetera.</td>
<td></td>
</tr>
<tr>
<td>Abnormal Configurational Naevi, (AConN)</td>
<td>cyclindroma, seborrhoeic naevus, verrucous naevus, seborrhoeic hyperkeratosis, acrochordon, miliaria, facial papules in Bourneville-Pringle’s disease, etcetera.</td>
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</table>
The range of depth of the blood vessels must also be carefully examined and taken into consideration in deciding treatment. In the composite type of haemangioma simplex (port wine stain), for example, abnormal blood vessels can be found at all depths from superficial to deep dermal and even subdermal. In this situation, the naevus must be treated layer by layer, using the wavelength- and pigment-dependent characteristics of a number of laser types to remove the abnormal vessels from the superficial layers down. Attempts to treat all of the range of blood vessels at once over a large area will certainly produce undesirable scarring, and this is where the poor results reported in the literature may stem from.

**Melanin anomaly group**

The abnormal colour of naevi of the melanin anomaly group is due to an excessive production of the biologic pigment melanin. In the case of vitiligo, the melanin production is less than normal, or totally absent, giving a depigmented lesion. Because of the nature of the pigment formation of these naevi, this group is classified as the static pigment group. C/W lasers can be very effective in treating this group, but pulsed dye or Q-switched lasers are also very effective. Again, the pigment depth and deposition varies greatly, even in the one patient, and the clinician must remove the pigment layer by layer, starting from the most superficial layers. Ohta's naevus is a good example of a multilayered static group naevus, and has often been reported in the international literature as very difficult or even almost impossible to treat. However, using the layer technique with a combination of conventional treatments and a variety of lasers the author has successfully and consistently treated a large number of these cases with a good result and few recurrence.

**Other laser application in PRS**

In addition to laser treatment for naevi, some other interesting applications of the laser have been reported in PRS, but they underscore the importance of the many effective features of a group of techniques, the combination of which may provide a synergistic effect which will give a better treatment result than if the techniques were applied singly. They include postoperative pain attenuation, improvement of local circulation and therapy for diseases involving circulatory impairment, and control of postoperative or posttraumatic haematoma.

**Laser welding**

Collagen fibre bundles, which form a major part of dermal tissue architecture, are held together by cross-linking hydrogen bonds. These bonds are susceptible to heat, and at temperatures in excess of 40°C they break down. On cooling, the bonds reform, although recent reports suggest this is noncovalent rebonding. With careful temperature control, two blocks of tissue can in theory be joined by this denaturation-renaturation process by a weld of living collagen tissue. Reports on tissue welding for sutureless microanastomosis were appearing in the literature in 1980, followed by laser welding of neural tissue and finally of cutaneous wounds. Recent studies have shown that cutaneous tissue welding can be enhanced by application of a topical photosensitizing dye. Simultaneous LLLT may also have a role in the success of such welding applications.

**Conclusions**

With every international and national meeting, new or improved laser applications are reported in many specialties, including PRS. For laser treatment to be consistently successful, however, the laser clinician needs an in-depth understanding of a large and wide variety of fields, in addition to the ability to form a solid physician-patient rapport, excellent surgical skill and a sound knowledge of anatomy; these include basic laser physics; photobiology; laser-tissue reaction; microcellular biology; and laser system repair, maintenance and set-up. With all of that knowledge of photodestruction and photoactivation (HLLT and LLLT) in place, the plastic and reconstructive surgeon should be confident of moving forward into the 21st century with full control of what is surely becoming the surgical tool of the future; the medical and surgical laser.

**References**