Intense Pulsed Light – The Relevance of Constant Spectral Output with Large Spot Size on Tissue

a report by

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The recent rapid growth in demand for non-invasive cosmetic light-based treatments has led to a boom in the sale of medical devices that treat a range of skin conditions. Medical and cosmetic conditions being treated include unwanted facial and body hair, age-related sun-damaged skin, changes in pigmentation, vascular blemishes and early signs of ageing such as lines and wrinkles. The often onerous safety regulations governing the sale and use of class 4 lasers has contributed to the popularity of similarly powerful non-laser intense pulsed light (IPL) sources, particularly in the salon and spa sector. This paper reviews key issues that impact directly on efficacy and safety of treatment procedures using an innovative approach to white light therapy. All outcomes reported have been achieved using a constant spectrum intense flash lamp device (iPulse™ i200 IPL, Cyden, Wales, UK) without the need for parallel skin cooling or multiple absorption filters.

Selective Photothermolysis

Anderson et al. first proposed the concept of selective photothermolysis in 1981, being an optical process where light incident on tissue is preferentially absorbed by a target component in the tissue and largely ignored by other tissue structures.[1] The light energy absorbed in the target (the chromophore) is then converted into heat. The heat in turn is controlled to induce the desired therapeutic effect. The primary relevant chromophores in the skin are melanin, the epidermis pigment (also found in hair), and haemoglobin, the red pigment in blood and other tissue. The absorption curve for the oxyhaemoglobin in blood contains a number of peaks. These can be used to induce a range of positive therapeutic outcomes. By careful control of optical parameters, a range of therapeutic outcomes can be achieved; for example fine thread veins and small superficial vessels may be eliminated, usually over several treatments. Melanin is a chromophore that can be targeted by a range of wavelengths. If the desired target is the hair shaft then longer wavelengths such as red (circa 700nm) are optimal since their penetration into tissue is greater. If, on the other hand, issues of epidermal pigment such as age spots are the problem, then it is better to use green wavelengths (circa 530nm) to remove the lesion. White light systems deliver a broad range of wavelengths and can therefore be used to treat a number of skin conditions.

Hair Removal with Intense Pulsed Light

Hair removal using laser systems was initially introduced onto the market in the mid-1990s.[2,3] These systems were monochromatic – in other words emitted one pure wavelength or colour of light. In the new millennium, white-light emitting IPL technology emerged as a powerful competitor and challenged the dominance of the laser in the market.

The recent success of IPL as a tool for long-term hair removal (‘permanent hair reduction’) has largely been based upon the use of high-energy exposure. Such intense flashes of white light are transmitted through the upper layer of skin, the epidermis, and absorbed in the melanin present in the hair shaft. The process leads to damage of the hair follicle and results in suppression of hair growth. As melanin absorbs energy relatively efficiently across a wide range of optical wavelengths, this fact has made white light systems the current technology of choice. Some authors have suggested that the longer wavelengths that are absorbed in blood and tissue water may also play a role in the hair removal process. It is claimed that these wavelengths cumulatively damage hair follicle support structures such as the blood supply to the hair bulb. The relatively large spot sizes used together with the wide range of wavelengths may also go some way to provide depth of light penetration to the underlying follicle. However, current approaches to long-term hair growth delay remain relatively unsophisticated and it is generally accepted that technology and science will lead to further developments that will improve efficacy and reduce further the incidence of unwanted side effects.

In initial trials with iPulse IPL, an analysis of the treated areas showed that the hair density had dropped from an average of 48 per cm^2 pre-treatment to 19 per cm^2 45 days post, equating to a 60.4% reduction in hair density. Subsequent trials by Omi and Clement on Asian skin types and Ancona, Stuve and Trelles in a multicentre European trial have confirmed the efficacy of iPulse technology in long-term hair growth delay.[4,5]

Photo-rejuvenation

Photo-rejuvenation is the use of light to renew skin and can take place in both the epidermis and dermis. Shorter wavelengths are highly absorbed in the melanin and problems of pigment can be addressed. This epidermal ‘photo-rejuvenation’ can include improving skin dischromia and multiple treatments with high-power IPL devices can reduce

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epidermal melanin in photo-damaged skin, and some cosmetic benefit has been reported after multiple treatments[6–8] (see *Figure 1*).

Dermal rejuvenation takes place deeper in the skin. The concept was first postulated in 2000[9,10] when the US Food and Drug Administration (FDA) approved a laser system for the 'improvement in the appearance of wrinkles'. Bjerring et al. suggested that the mechanism responsible for skin rejuvenation was that of an 'optically induced wound healing cascade'. Yellow light is preferentially absorbed in the blood chromophore (oxyhaemoglobin) and deposits a controlled amount of energy in the skin's microvasculature. This interaction then leads to the initiation of the natural wound healing response of the skin. Mediators released into the dermis stimulate collagen production from fibroblasts resulting in photo-rejuvenation. Early work undertaken with laser systems has been replicated to a degree with white light systems where the yellow portion of the emitted spectrum is absorbed in the blood and initiates the wound-healing cascade.

Spectral Control

In contrast to monochromatic laser sources, IPLs provide an intense broadband output that generally covers both the superficial melanin absorption area (green) and the haemoglobin absorption area (yellow) but also extends into the red region, which provides deeper penetration into tissue. The interaction of these multiple wavelengths with the skin is sufficiently selective to treat vascular lesions with yellow light around 578nm (the absorption peak of haemoglobin) and superficial pigmented lesions with green light around 530nm where melanin absorption is highest. The red output (circa 700nm) gives less scatter and deeper penetration and the melanin absorption curve ensures good absorption in even deep-lying hair follicles.

Despite these advantages there is much opportunity to improve the efficacy of white light systems. It is particularly important to consider how the optical output energy is distributed across the broad output spectrum. This energy 'sharing' within the wavelengths is further complicated by the fact that in traditional IPL systems it is a dynamic process. Energy distribution across the wavelengths at the start, middle and end of the pulse may not be the same. The energy distribution varies during the period of the pulse resulting in 'spectral jitter'.[11]

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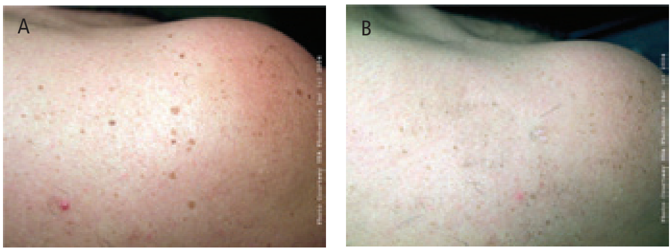
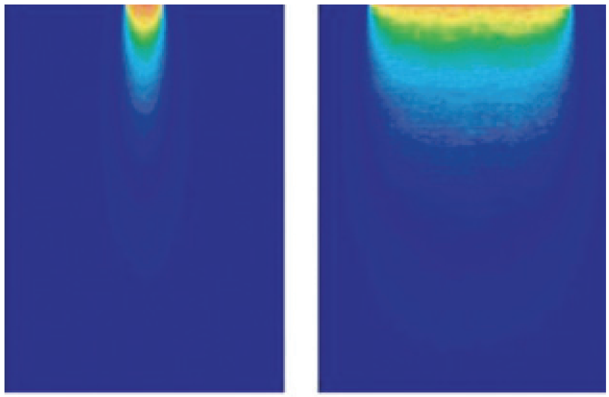
Conventional high-power IPL white light systems use free-discharge technology, i.e. electrical energy is stored and then released from a capacitor bank into the xenon lamp. Such technology allows current in the discharge to build up from a low level, reach a peak and then fall away again. This results in a plasma discharge in the xenon that runs cold, heats up and then cools again. The variable high-density current discharge produces a spectral output that shifts towards the blue end of the visible electromagnetic spectrum as the discharge current density rises and back towards the red end as the energy pulse tails off. This effect of spectral jitter during the pulse means that the spectral output

Figure 1a/1b: Typical iPulse Single Upper Back Treatment of Benign Pigmented Lesions Showing Before and at 21 Days Post-treatment Using 14J/cm² with a Triple Pulse (14ms on, 7ms off)



Immediately post treatment, the lesions appeared darker with peri-lesional inflammation. Over the following three to four days, the lesions darkened and localised scabbing formed, which resolved in <14 days.

Figure 2: Larger Beam Width is Far More Effective in Achieving Depth of Penetration than the Same Energy (Per cm²) Delivered in a Small Spot Size



As a result, the iPulse system uses less energy to achieve greater treatment efficacy.

not only varies during the pulse but also differs significantly from one energy setting to another. This can mean that much of the pulse output is at wavelengths that are not useful for targeting chromophores in question and much of the potentially useful energy is wasted, i.e. the 'effective' pulse duration may be much shorter than intended and thus rendered less effective.

The iPulse system uses partial discharge technology, which in simple terms means that a large value capacitor is fully charged but only partially discharged during every pulse. Using a sophisticated computer control system and a low-power xenon lamp, a constant current discharge can be achieved ('top-hat' profile). This means that the current in the xenon is constant throughout the pulse. The wavelengths emitted are also therefore constant throughout the pulse and spectral jitter is eliminated. Thus, at any instant during the pulse the wavelength sharing will be the same. This control of spectral output leads to greater efficiency and efficacy of treatment.

Using an Ocean Optics HR2000+ spectrometer and its counterpart Spectra Suite software (OceanOptics, Dunedin, FL) allows sampling of the IPL spectrum of light with a minimum integration time of 1ms. Time-resolved spectral data modelled using Mathcad™ software allows comparison of spectral distribution and confirms effective pulse duration rather than total pulse duration.

Spatial Control

Most conventional IPL devices use a single linear high-power xenon flashlamp configuration. This leads to an elongated rectangular treatment 'footprint' on tissue. The plasma in all flashlamp discharges has a concentration towards the centre of the lamp tube. This invariably results in a 'hot spot' near the lamp centre that can be only partly mitigated by the optical system delivering the light energy to the tissue.

The iPulse system uses twin low-power xenon lamps enclosed in an optical system designed to ensure that the energy distribution on tissue is spatially uniform. Traditional single-flashlamp systems typically result in a 'long and thin' footprint on tissue. Such configurations lead to significant scatter of light away from the treatment area as the light is transmitted through the skin, thus wasting energy and reducing efficacy.

The design philosophy for iPulse allows a more beneficial area–edge ratio and larger spot size area of 8.9cm^2. This means less need for overlapping pulses, it ensures efficient delivery of photons into tissue by minimising scattering through perimeter losses and guarantees that the heat distribution in the skin is uniform across the entire treatment area.

Conclusions

The iPulse system is a significant advance over traditional IPL technology. The partial discharge technology developed permits output spectral control and eliminates spectral jitter. This allows the operator to be confident that wavelength outputs are consistent and constant throughout the pulse. The result is the ability to treat conditions at lower fluences, increasing efficacy and reducing side effects.

IPL with iPulse technology provides a constant output of suitable wavelengths and energy densities for repeated treatments to achieve permanent hair reduction as well as single-step treatment of most epidermal benign pigmented lesions. These results were achieved without unacceptable patient discomfort or side effects. ■

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