Scientific Evaluation of VSP Nd:YAG Lasers for Hair Removal

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Abstract
A variety of laser systems with varying wavelengths, pulse durations, spotsizes and energy fluences are currently used for hair removal. In this paper VSP Nd:YAG laser efficacy and safety were evaluated. We found that the modern, high-power, second generation VSP Nd:YAG laser systems with cold air cooling and scanner technology gave the best possibilities to adjust treatment parameters to the individual cases and thus optimize treatment efficacy while preserving the epidermis from unwanted damage.

Key words: laser hair removal; VSP technology, Nd:YAG lasers, scanner

INTRODUCTION

Laser hair removal has in recent years received wide clinical acceptance in both medical and aesthetics settings, because of its long-term results, non-invasive nature, minimal treatment discomfort, and the speed and ease with which procedures can be performed [1]. Commercial laser and flashlamp light (IPL) systems differ in wavelength, pulse duration, fluence, laser beam delivery system and skin cooling method; all of which have an effect on the outcome of the treatment. When deciding on the most appropriate light source for laser hair removal treatments, tissue interactions should be thoroughly studied and taken into consideration. The various light sources currently available for hair removal include IPL (broad spectrum), ruby lasers (694 nm), alexandrite lasers (755 nm), diode lasers (810 nm), and Nd:YAG lasers (1064 nm). This study was designed to scientifically evaluate the safety and efficacy of the VSP (Variable Square Pulse) [2] Nd:YAG laser and compare it to other commercially available light sources.

Achieving satisfactory results, when using laser to treat unwanted hair, depends on many factors. It has been demonstrated that successful permanent unwanted hair removal can only be achieved by injuring the bulb, the bulge and the outer root sheath of the hair follicle.[1] Therefore the region in which these structures lie is the target for any method used to create the required injury to permanently remove hair. During the process of laser and light-based hair removal, light is absorbed by chromophores (usually melanin in the hair shaft and follicle) and transformed into heat energy, resulting in a rise of the hair temperature. When the temperature is high enough, irreversible damage occurs to the hair structures, thus preventing or altering the growth of the hair. Success is determined by tissue physics, hair physiology and the device used in the treatment. In order to select an effective laser hair removal device, one must understand how each laser and light source produces its specific biologic effect on tissue. The following characteristics and parameters need to be considered: wavelength, pulsewidth, pulse shape, spotsize, fluence, treatment speed and epidermal cooling method.

WAVELENGTH CONSIDERATIONS

The choice of wavelength is dictated by the need for good absorption of the laser or light energy, in the hair follicle lying deep in the skin, while avoiding unnecessary damage to the epidermis. Successful hair removal treatments require light to penetrate deep into the skin because it is necessary to destroy the entire follicle. Depending on the location on the body, light must penetrate 2 to 7 mm into the skin to be effective [3].

The optical properties of human skin are determined by two processes: absorption and scattering of light.

Absorption

For the absorption of incident light energy, assuming no scattering, the beam intensity is described by the equation:

$$I(z) = I_o \, e^{(-\alpha z)} \qquad (1)$$

where z is the depth, α absorption coefficient and I_o the Intensity of the laser beam on the surface of the

skin.

In day to day practice a more illustrative parameter is penetration depth *δ*, defined as

$$\delta = 1/\alpha \qquad (2)$$

which tells you at which depth the intensity of the laser beam falls to the level 1/e (36,78%) of incident laser beam.

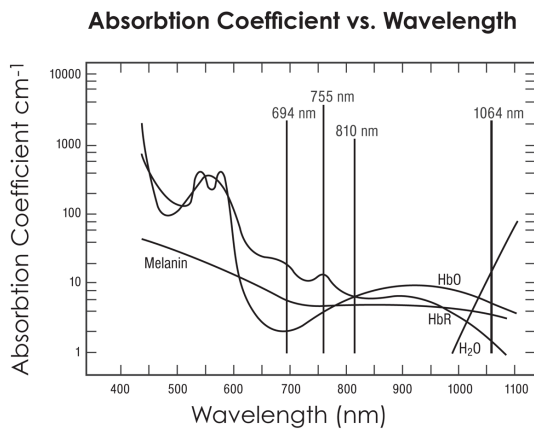Fig. 1 shows the absorption characteristics of various skin chromophores.

Absorbtion Coefficient vs. Wavelength

Fig. 1. Absorption characteristics.

Since light is absorbed by hair melanin throughout the visible light and near infra red spectrum, there are numerous wavelengths that can theoretically be effectively utilized. However, strong absorption in hemoglobin in small superficial blood vessels prevents light sources in the 400-590 nm wavelength range from penetrating deep enough to have an effect on the hair follicle in hair removal treatments. Early hair removal devices concentrated on wavelengths in the 650-850 nm range (ruby laser at 694 nm, alexandrite laser at 755nm, diode laser at 810 nm), because of their high absorption in melanin [4]. However, as skin color darkens with increased amounts of melanin, penetration depth decreases due to competition between melanin in the skin and melanin in the hair. In addition, since the epidermis contains relatively high concentrations of melanin [1], laser light is more readily absorbed, therefore increasing the risk of undesired thermal injury to the epidermis resulting in more pain and side effects. For this reason, the latest generation hair removal devices are based on laser sources with longer wavelengths. Nd:YAG laser devices hold the most prominent position due to its long wavelength of 1064 nm which in terms of absorption lies in an optical window that allow light of this wavelength to penetrate deep into the skin, while its absorption in the hair follicle is strong enough to

destroy hair follicles. Furthermore, Nd:YAG laser technology is a widely-used and mature technology which has led to these laser systems having very high lasing efficiency and beam quality.

Scattering

In addition to absorption according to Eq.1, the effect of light scattering in the human tissue must be considered. Scattering of laser light substantially influences the beam propagation through tissue and thus effects absorption [5,6]. [Fig 2]
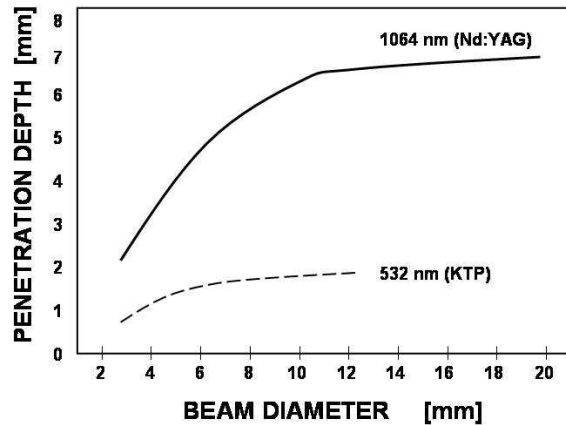

Fig. 2. Penetration depth depends on beam diameter and laser wavelength.

Once light penetrates into the dermis, the depth of penetration becomes strongly influenced by scattering. The degree of laser light scatter in the skin before reaching the target chromophores, and therefore preventing any effect on the target, depends on the laser wavelength. Fig. 3 shows the dependence of the scattering coefficient in skin on laser wavelength. A high scattering coefficient corresponds to high scattering in the skin and therefore short penetration depths. As can be seen from Fig. 3, the Nd:YAG laser has a low scattering coefficient and thus penetrates deeper compared to other laser wavelengths that are also used in laser hair removal treatments.
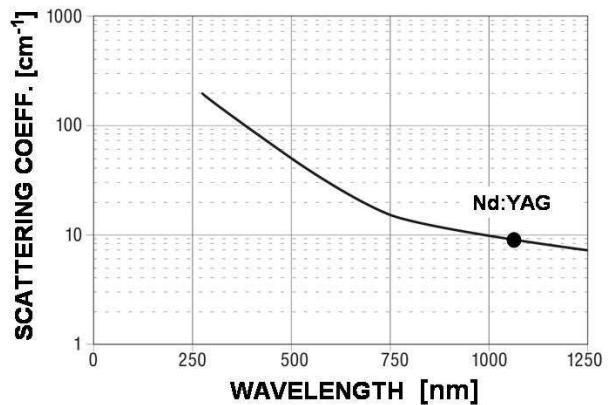

Fig. 3. A log plot of the scattering coefficient for skin as a function of wavelength. Note that the scattering effect decreases with increasing wavelength.

After several scattering events, light no longer travels unidirectionally in the skin; its direction becomes random [Fig. 4], causing the light to bounce back and forth inside the skin, until it is absorbed in one of the skin chromophores (for example in a hair follicle). By traveling randomly in skin at this point, the probability of light affecting skin chromophores becomes higher than if it were to travel through the skin unidirectionally. This effect in fact further enhances the absorption of Nd:YAG laser light in hair structures making this wavelength extremely effective for hair removal.
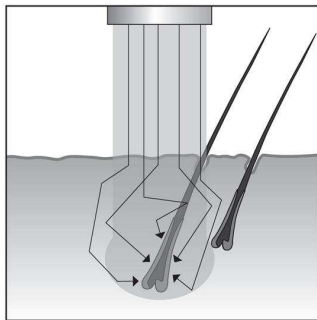

Fig. 4. Random beam scattering. Due to scattering the light gets trapped in the absorbing elements such as hair follicle.

In order to penetrate as deep as the Nd:YAG laser, other wavelengths require the use of larger spotsizes and consequently more energy to achieve the same clinical effect. The influence of spotsize on the penetration depth and the energies required to attain a certain clinical effect are explained in more detail further in this paper. To reach the same depth, a ruby laser would thus require a larger spotsize and energy than an alexandrite laser, an alexandrite laser in turn requires a larger spotsize and energy than a diode laser and a diode would require a larger spotsize and energy than a Nd:YAG laser.

Intense Pulse Light (IPL) devices are sometimes used in aesthetics. These devices emit a very broad wavelength spectrum of light and are therefore not as selective and fine-tuned to particular target tissue absorption characteristics. They have average absorption characteristic and average scattering phenomena.

PULSEWIDTH CONSIDERATIONS

Selective Photothermolysis

Since it is clinically desirable to selectively treat the hair follicle without producing any injury to the surrounding tissue, laser energy is always delivered in single, short pulses. The target tissue approaches its maximum temperature once the laser pulse has ended. It then cools by transferring the heat to the adjacent

tissue. The time required for the target tissue temperature to decrease by 63% is the thermal relaxation time (TRT). In order to destroy the target tissue and to avoid damage to surrounding tissue, the laser pulse duration (pulsewidth) should be lower or approximately the target tissue's TRT. To avoid unwanted injury to surrounding tissue, the laser pulsewidth should be much longer than the TRT of the surrounding tissue.

Because the epidermis is the first tissue exposed to the incoming beam of light, injury to the epidermis is most likely to occur, but only if the energy is delivered in too short a period of time. For this reason, the pulsewidth should exceed the TRT of the epidermis. Likewise, in order to injure the hair follicle, the laser energy must be delivered in a pulse of which the duration is shorter than or equal to the follicle's TRT. If the pulse is too long, the follicle will be able to dissipate the energy before reaching a temperature that will destroy the follicle. The TRT of the epidermis is estimated to be between 3 and 7 msec [1], depending on its thickness. The TRT for a hair follicle is estimated to be between 1 and 100 msec [1], depending on its diameter. The thinner the hair - the shorter its TRT. Ideally, laser systems for hair removal must be capable of delivering laser pulses with a pulsewidth longer than the TRT of the epidermis (e.g. 5 msec), but shorter than the TRT of the treated hair follicle (e.g. 15 msec). [Fig. 5, Fig. 6] Some commercial devices are capable of producing sufficient energy in pulsewidth durations that fall within these specifications, but many devices, especially diode lasers and IPL devices are not. Namely their pulse power generating capacity is not high enough to deliver sufficient energy in short enough pulsewidth durations.
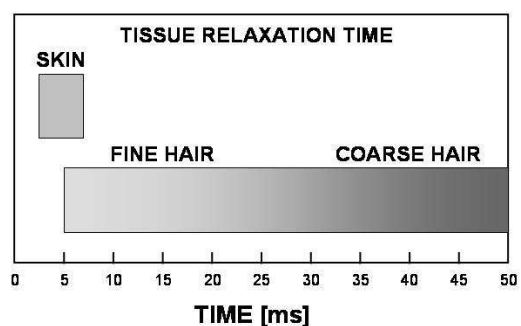

Fig. 5: Ranges of tissue relaxation times.

In Fig. 6 it is demonstrated that in short laser pulses (short pulsewidth) the TRT of the epidermis is reached while in long laser pulses (long pulsewidth) it is not. Short laser pulses are therefore more likely to cause injury to the epidermis than long laser pulses.
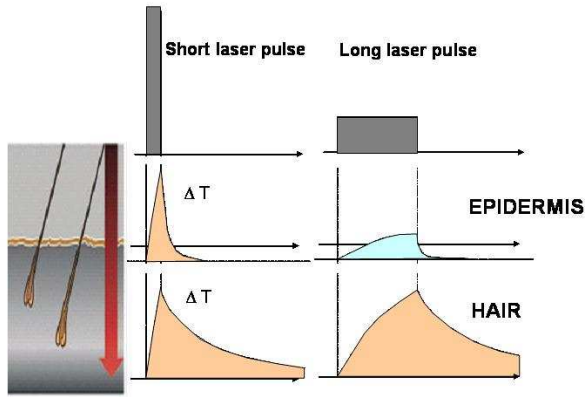
Fig. 6: The rise in epidermal and hair follicle temperature is dependent on the laser pulse duration.

VARIABLE SQUARE PULSE TECHNOLOGY

As discussed, light energy must be delivered into the skin in appropriately short pulses to be safe, and yet remain effective by thermally only affecting the desired target tissues. To generate light pulses with a high enough energy content to be effective, most devices rely on standard Pulse Forming Network (PFN) technology. PFN pulses have a typical temporal shape (shown in Fig. 7) with a slow rise time and a relatively long declining tail; the pulse power is not constant during the pulse and the exact pulsewidth is not defined. While PFN pulses have been shown to be useful and effective for hair removal; newer, more advanced Variable Square Pulse (VSP) technology generates pulses that provide much higher treatment precision, efficacy and safety. Fig. 7 shows a square pulse generated using VSP technology compared to a standard laser pulse. A significant difference between the two types of pulses is that the average power and the peak power of a square pulse is nearly the same, which cannot be said for PFN generated pulses. This means that the effect of VSP pulses on the skin is far more predictable than PFN pulses, which ultimately leads to superior treatment outcomes, with less discomfort and fewer side effects.
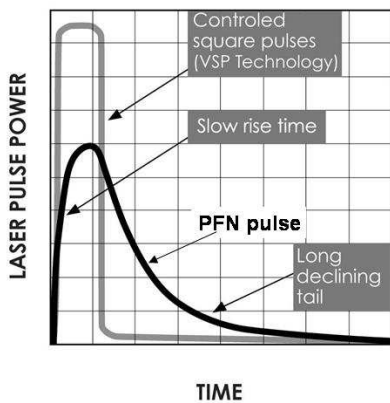

Fig. 7. Comparisons between PFN and VSP shaped pulses.

An additional advantage of VSP technology is that it allows the user to easily adjust the pulsewidth and laser power, or even form a controlled train of micropulses within a larger overall pulse thereby optimizing the efficacy and safety of treatments, by making each pulse with a particular pulsewidth completely predictable from a clinical outcome point of view.

Second generation VSP Technology

The majority of first generation hair removal laser systems produce pulses that are significantly shorter in duration than the epidermal TRT. This causes excessive injury to the epidermis and unwanted side effects. Second generation Nd:YAG laser systems based on the Pulse Forming Network (PFN) technology are capable of producing laser pulses of longer durations. However, many of these second generation systems use a "double pulse" method that may be misleading to the user. Fig. 8 shows a typical double pulse sequence emitted by a PFN Nd:YAG laser system and shows how laser energy is emitted in two single micropulses separated by a time period that is defined by such devices as the laser pulsewidth. This method does not improve safety for the epidermis since most of the heating is achieved within short periods of micropulses. Since all the laser energy must be delivered in two micropulses, the single pulse energy, and therefore instantaneous temperature increase is relatively high. Note also that the second pulse does not contain much energy and that therefore most of the energy is contained in the first pulse.
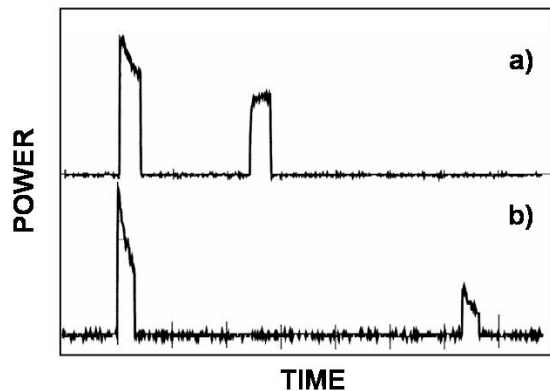

Fig. 8. A typical two pulse sequence of some PFN Nd:YAG laser devices: pulsewidth is simply adjusted by changing the interval between two pulses.

The pulse structure of Variable Square Pulse (VSP) technology Nd:YAG laser systems is much better adjusted to the TRT requirements of skin tissue. Fig. 9 shows a typical pulse structure of a VSP laser pulse. The overall pulsewidth is increased by adding more micropulses to the overall laser pulse, and not just by increasing the separation between two micropulses.

Also, the energy is distributed evenly over all micropulses. This ensures that the pulse width can be optimized to the particular TRT's of the epidermis and the hair follicles.
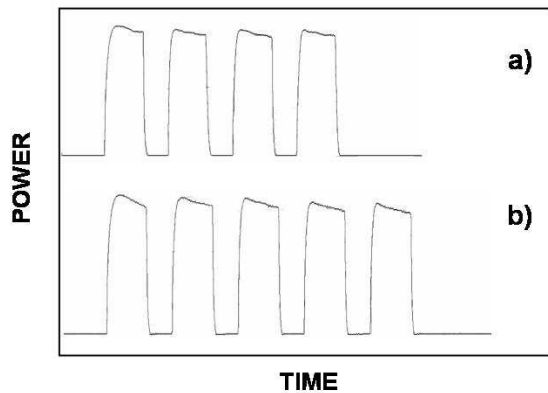

Fig. 9. A typical VSP pulse structure for different pulse durations: a) Fotona Versa mode 11ms; b) Fotona Versa mode 14ms.

When treating patients with lighter skin and thinner hair, VSP technology allows the practitioner to select a special ACCELERA mode. In this particular mode the micropulse duration is further reduced in order to generate higher instantaneous laser powers and local temperatures of the hair follicle. To treat extremely thin or light color hair follicles, VSP technology allows the practitioner to decrease micropulse widths to 0,1 msec. In conclusion, VSP Nd:YAG laser systems provide the necessary precision and versatility to match the pulsewidth with the appropriate amount of fluence (energy density) necessary to cause effective follicular damage.

PULSE ENERGY AND FLUENCE CONSIDERATIONS

Fluence

The fluence is one of the main settings for hair removal. It is defined as energy density:

$$f = E/S \qquad (3)$$

where f is fluence, E is the energy of the laser pulse and S is the spotsize of the laser beam at the skin surface. Usually it is measured in J/cm^2.

The typical Nd:YAG fluence values for hair removal range between 30 to 100 J/cm^2 [5,7,8].

Beam profile

Standard laser handpieces emit beams with a Gaussian profile with an energy distribution that resembles a conical shaped curve [Fig. 10a]. The principal effect of this is to create higher focal fluences at the centre of the spot while the fluence decreases towards the edge of the spot. Gaussian profile handpieces are less appropriate for laser hair removal treatments where a uniform fluence is desired over the whole spot. However, they might be very useful for treating vascular lesions.

Special *"top-hat"* profiled handpieces (such as Fotona R33, R34, and S11) have been developed for hair removal [Fig. 10b, Fig. 11].
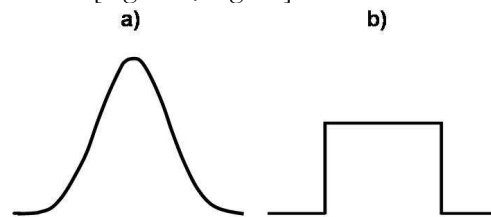

Fig. 10. a.) A Gaussian beam profile
b). A top-hat beam profile

Fig. 11. An example of a top hat profile 20 mm spot size handpiece (Fotona R34).

Because of their much more homogeneous beam profile, top-hat handpieces are much safer and effective compared to standard Gaussian profile handpieces. For example, Fig. 12 shows that for a selected fluence on the laser keyboard (which is in reality only the average fluence), a 4 mm spot with a "Gaussian" handpiece, will emit laser radiation in the center of the spot with a focal fluence twice the value of the "top-hat" handpiece, and practically zero fluence at the edges of the spot. If a 60 J/cm^2 fluence value is selected on the keyboard the "Gaussian" handpiece will emit 120 J/cm^2 at the center of the spot.
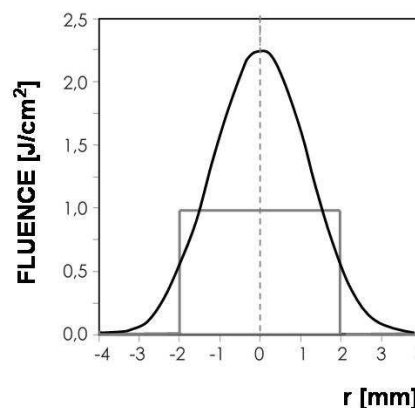

Fig. 12. Comparison of peak fluences of Gaussian and top-hat beam profiles for the same average fluence and 4 mm spotsize.

It is important to note that where a user is used to treating unwanted hair with a top-hat handpiece at certain selected fluences, a much lower fluence setting is required when working with a Gaussian handpiece. This is because for the same (average) selected fluence, the fluence at the center of the spot is much higher with a Gaussian handpiece, .i.e. 3.8 times higher with a 2 mm spot, 3.1 times higher with a 3 mm spot and 2 times higher with a 4 mm spot.

SPOTSIZE CONSIDERATIONS

The inexperienced laser system user may not always recognize the importance of the spotsize of the emitted beam as a treatment parameter. Theoretically, if the spotsize is increased and the laser energy is simultaneously increased to maintain the same energy fluence, the clinical effect should be similar. However, due to random laser light scattering, spotsize does make a difference to the treatment outcome. As a beam propagates into the skin, light scattering spreads the beam radially outward, which decreases the beam's intensity as it penetrates into the skin. This effect is more pronounced in smaller spotsizes where the penetration depth is much lower than it would, if only absorption characteristics were considered.

Fig. 13 shows the deposition of laser energy within the skin for three different spotsizes (2, 6 and 20 mm) for the same laser fluence of 60 J/cm², based on our computer simulations. A Monte Carlo numerical method [9] was used to obtain these results.

As can be seen in Fig. 12 the depth of laser energy penetration increases with increasing spotsize. For example, the same energy deposition of 10 J/cm³ is achieved at 1.6mm, 3.7 mm and 7.5 mm (depth of efficacy) for respective spotsizes of 2, 6 and 20 mm. This means that in principle small spotsizes (e.g. 2-3 mm) are good for treatments where heat has to be deposited superficially in the skin, as in skin rejuvenation and treatment of vascular lesions. Following the same reasoning, larger spotsizes are better for laser hair removal treatments because the aim of these treatments is to achieve thermal effects deep in the skin, where the hair follicles are located. However, the more tissue light has to thermally affect, the more energy is needed from the laser system. This means that in practice it is important to optimize the spotsize and therefore the penetration depth to the actual depths of the hair follicles.

It is important to note that the sensation of pain also increases with the laser spotsize. The larger the spotsize, the more discomfort is felt by the patient [Fig. 14]. For this reason it is advisable not to use a spotsize that is larger than needed to reach the necessary depth where hair follicles are located. Also, scanning a large area with a large number of smaller laser spots with a scanner is therefore preferable to

covering the same area with a small number of large laser spots.
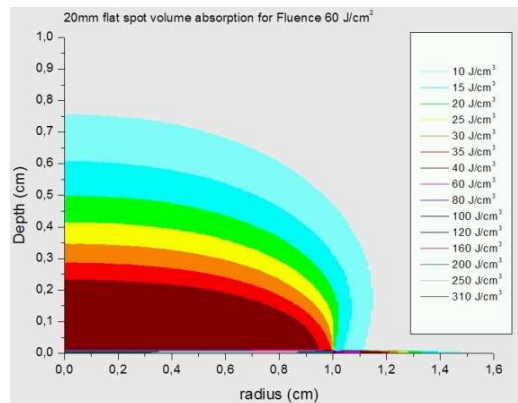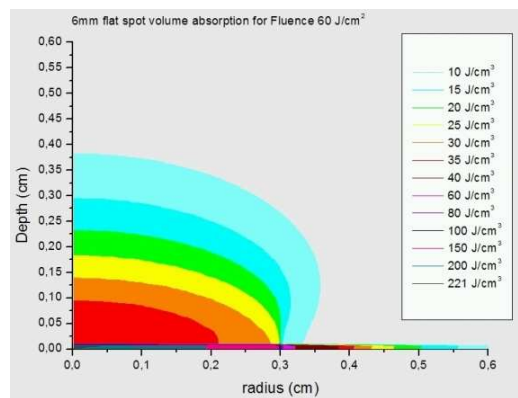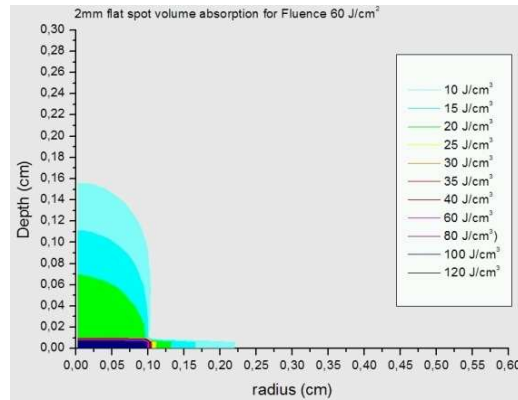

Fig. 13. Computer simulated deposition of laser energy within the skin for three different spotsizes (2, 6 and 20 mm) for the same laser fluence of 60 J/cm² .
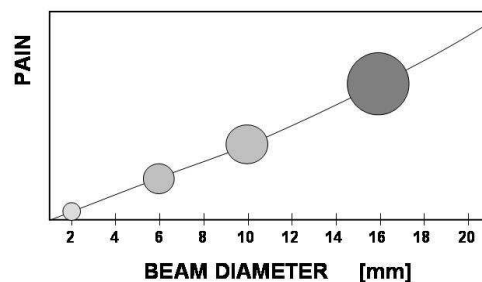

Fig. 14. Pain perception dependence on beam size.

TREATMENT SPEED AND PRECISION CONSIDERATIONS – LASER SCANNER

Larger spotsizes may be preferred by regular laser system users as they allow faster coverage of the treatment area. However, this may not be the optimal choice. The process of absorbing and scattering means that energy becomes concentrated in the superficial epidermal layer. The larger the spotsize, the larger the volume of skin from which laser light can be scattered back and absorbed in the epidermis. This means that the epidermis is heated more when larger spotsizes are used. Fig. 13 shows that for the same laser fluence the energy deposited in the superficial epidermal layer is 120, 221 and 310 J/cm^3 for spotsizes 2, 6, and 20 mm respectively. Consequently, although with larger spotsizes laser light penetrates much deeper into the skin, the level of unwanted epidermal heating increases. To avoid this effect, it is advisable to reduce fluences as spotsizes are increased, or to significantly increase the level of epidermal cooling. These two factors combined indicate that while larger spots penetrate much deeper into the skin they are not necessarily as safe and comfortable as medium spotsizes.

To strike the right balance between spotsize, fluence and penetration depth, a computer controlled SOE (Scanner Optimiued Efficacy) technology has been intrioduced.
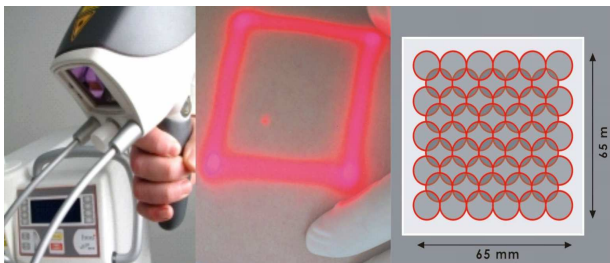

Fig. 17: An example of a VSP Nd:YAG laser scanner (Fotona S11)

A scanner allows the use of medium spotsizes to cover large skin areas without sacrificing the treatment speed and efficiency. Advanced scanners, such as the S-11 from Fotona, based on SOE technology [10], utilizes top-hat distribution technology to minimize hot spots in the scanning pattern [Fig. 18]. The S-11 scanner also allows users to select a small spotsize (3 mm) for shallower skin rejuvenation treatments, and medium spotsizes (6mm and 9mm) that are capable of penetrating deep enough to ensure effective hair removal treatments while maximizing patient safety and comfort. Combined with a large scan area of 6.5cm x 6.5 cm (42cm²) and high coverage speeds, the S-11 scanner is one of the most efficient means of providing laser hair removal.
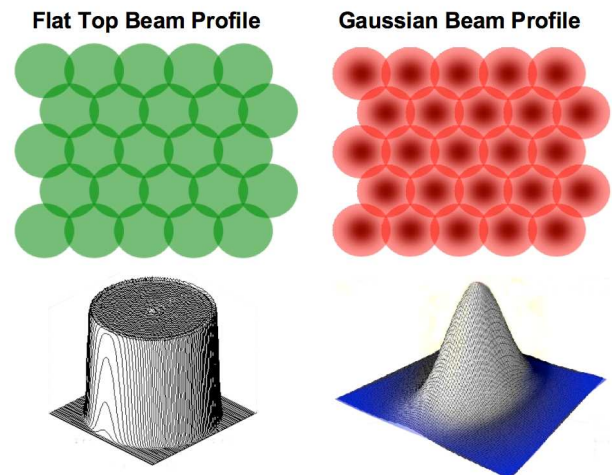

Fig. 18. Top-hat profile scanning pattern without *"hot-spots"* compared to Gausion profile scanning pattern with hot-spots.

Another important advantage of using a scanner is spots can be placed far more precisely than manually covering the same area with a handpiece and individual spots. Ideally, visual tissue effects are minimal during laser hair removal treatments and it is therefore quite difficult to distinguish treated areas from non-treated ones. Inevitably the area covered with a scanner is larger than the area covered with individual spots, which simplifies the alignment of treatment passes over the treatment area. The risk of accidental overlap and thus excess thermal heating and spread is decreased. The use of a scanner decreases treatment time, increases the precision of energy placement on the tissue, therefore decreasing fatigue and ensuring treatment safety.

Long-term clinical experience has shown that the use of a scanner significantly reduces discomfort during the treatment. Since the coverage is computer-controlled, the laser spots do not have to be applied onto the skin sequentially next to one another, as would be the case in a manually performed treatment. For example, the Fotona S-11 scanner is able to scan the entire scan area during the given time period without ever depositing one spot directly next to another. The scanning sequence 'skips' spots and lines, with the 'gaps' being filled in progressively with each pass. In this way it requires four passes to cover the entire scan area completely, doing this as fast as a single 'Sequential' pass. Such scanning sequence allows the user to perform hair removal treatments that require high fluence settings at high repetition rates.

EPIDERMAL COOLING CONSIDERATIONS

Light-based hair removal inevitably requires laser light to pass through the epidermis first before reaching the to-be-treated hair follicle. For this reason, it is important to be able to reduce any unnecessary heating of the epidermis by all means, to ensure patient comfort and avoid any irreversible damage to the skin. Epidermal cooling can be particularly helpful when treating patient with darker skin types. Besides choosing the laser wavelength with the lowest absorption in the epidermis, and tailoring the laser pulsewidth, as discussed in previous sections; epidermal cooling methods should be considered [11].

There are several skin cooling methods, all of which extract heat by conduction into an external, cold medium. The rate of epidermal cooling depends on temperature, contact quality, motion, and thermal properties of the external medium. An optimal cooling method should cool the epidermis, while not excessively cooling the hair shaft.

Cryogen spray

One cooling method consists of spraying the epidermis with a cryogenic spray. This spray instantly evaporates drawing heat from the epidermis. If applied correctly, the cooling will last for the duration of exposure to the laser energy. A new application is required for each epidermal area that is being lased. This is in principle a very precise, but at the same time a very aggressive cooling method that can cause damage to the epidermis if applied too heavily, or for too long. Cryogen-induced freezing injuries (permanent hypopigmentation) have been reported. On the other hand, since short application times are involved, any failure of the cryogenic device, due to the freezing of the instrument tubes and valves, will not be noticed until after the application of laser light only and will result in epidermal burning[22, 23]. In addition, if moisture is present in the air, small ice crystals (frost) will form on the sprayed surface, which can reflect a substantial part of the laser light. Cryogenic spray cooling methods only cool a very thin skin layer leaving the layers below virtually unprotected from unwanted thermal heating.

Contact cooling

Another method to cool the skin is to drag a constantly chilled metal paddle or a contact window along the treatment area immediately before the laser exposure. For optimum and safe results only the upper skin layer should be cooled, protecting the epidermis but not cooling down to the hair root. At present there is no method to accurately control the depth of cooling. Besides that the probes are usually large and cover the treatment area, thus reducing the visibility of the treated area, which slows the treatment time significantly.

Cold Air cooling

Cold air cooling is the latest method for active skin cooling (see Fig. 19). It delivers a continuous flow of chilled air before, during and after the laser exposure (pre-, parallel, and post-cooling). It provides more comfortable treatments (better analgesic effect for patients) and unlimited post-treatment cooling. Post-treatment cooling is important as it has been shown to reduce side effects and healing time. With cold air the treatment is more practical, safer and more pleasant. Faster treatments are possible since there is no need for time intervals to apply a cryogenic spray or contact cooling. The treatment area remains visible at all times during the treatment. The procedure is not dependent on surface topography facilitating access to specifi more complex areas i.e. bikini, intergluteal fold, ears, nostrils, etc. Furthermore, with this non-contact cooling method, there is no medium disturbing the path of the laser beam and no interface inducing energy losses caused by dispersion, transmission and reflections. Finally, it has no disposable requirements.

Fig. 19 A Fotona S-11 scanner with an air cooling flow nozzle.

While air cooling does not require any application of additional cooling gels it has been shown that air cooling efficiency can be additionally enhanced by applying laser gel on the treated skin area. This can be of benefit when high laser powers and high scanner repetition rates are used. The difference in skin temperatures that can be achieved using the gel is vividly demonstrated with a high-tech thermal imaging camera. Fig. 20 shows the effect that the gel has compared to skin that was cooled only by air. This additional cooling power means increased levels of patient comfort during treatments.
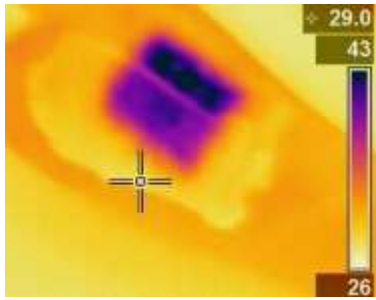
Fig. 20 The effect of Fotona Cool Skin Laser Gel on the air cooling efficacy.

The darker (upper) area is the skin cooled by air only, the lighter area (lower) is the area that has been treated with gel. The difference in temperatures is 14°C.

EYE SAFETY CONSIDERATIONS

Whenever using medical laser devices appropriate protective eyewear must be worn by the patient and all operating personnel to prevent inadvertent exposure to the eyes.

It is important to note that the same precaution applies also for intense pulse light (IPL) devices. These devices are sometimes marketed as simple light devices that are not dangerous to the eye. However, just the opposite is true and there have been clinical reports of eye-injury when working with IPL's. Studies [12] have shown that the IPL instruments actually imply a higher risk for eye-injury than a laser would for the same purpose and with much worse consequences. If an IPL light pulse is fired from a distance of 20 cm against an open eye, the MPE (Maximum Permissible Exposure) in the cornea can be exceeded by more than 4000 times. The MPE is according to IEC 825-1 standard the limit above which permanent eye-injuries can occur. IPL intensities are contrary to the general opinion dangerous to the eye. When coherent laser light is directed into an open eye, the light is because of the coherent nature of laser light focused on a very small spot on the retina and only a small part of the retina gets damaged. This is in fact the basis for laser eye surgery since such limited damage is usually not even noticed by a patient. On the other hand, IPL's non-coherent light is not focused on the retina and a much larger area of the retina will be damaged. The consequence of this is that while laser damage might not even be detected by the patient, IPL damage can cause blindness. IPL devices imply a much higher risk for eye-injury than would a laser for the same purpose and with consequences far worse. Since laser operates at a specific wavelength effective eye-protection is available as highly transparent eye-goggles that absorb light only at the laser wavelength. On the other hand,

since IPL emits light in a very broad spectrum there are no effective protection goggles since the visibility through such goggles would be very low. Eye protection for IPL devices is therefore difficult to achieve.

CLINICAL GUIDELINES

In laser hair removal laser settings must always be balanced in such a way that hair follicles are damaged while epidermal damage is avoided. When deciding on the treatment settings, first consider the structure of the hair and the skin type. To work safely test spots are highly recommended. It is recommended to reserve enough time between the test and the treatment to allow for any adverse effects to manifest. Secondly, settings should be set to accommodate the tolerance levels of the patient. In general, darker hair in darker skin types require lower fluence values and longer pulsewidths for effective and efficient hair removal.

A thicker hair will draw in more energy and hold the energy longer. Its TRT time is long and longer pulsewidths can be used. While the absorbed energy has to be kept below the damage threshold of the epidermis, lower fluences are usually used. In case of skin types I-III fluences up to 70 J/cm^2 and pulsewidths up to 50 ms can be used. Skin types IV-VI requiret more caution and fluences above 40 J/cm^2 are not recommended.

Thinner hair has a short TRT and the competition between melanin in epidermis and melanin in the hair is higher. The best clinical results are therefore obtained with higher fluence and shorter pulsewidth settings. Therefore. For such cases, the Accelera mode (available in Fotona devices) with very short micropulses has been found to be the most efficient and safe method to accomplish a satisfactory end result.

Light, blond hair requires even higher fluence values and shorter pulsewidths to be effectively and efficiently removed. Again, epidermal cooling is essential in such treatments.

Deep-lying hair follicles should be treated with larger spotsizes. As shown in Fig. 2, the deepest penetration of 7 mm can be achieved with a 20 mm spotsize. At these spotsizes heating of the central epidermal layer is increased due to back scattering of light [Fig. 13], and therefore the maximum applied fluence should not exceed approx. 35 J/cm^2. The laser energy required to achieve this fluence at a 20 mm spot size is approximately 110 J.

In most cases, the optimal spotsize for hair removal is between 6 and 9 mm, and with a top-hat laser beam profile. With such spotsizes hair follicles up to 4 mm deep [Fig. 2] are effectively damaged and the epidermis can be kept at safe temperatures with cold air epidermal cooling. In addition, such treatments are the

most comfortable to the patient.

Using the SOE technology it is very easy to cover large skin areas [Fig. 21][21], even with relatively small 6-9 mm spots. For example, with the Fotona S-11 scanner, a 6 mm spotsize, and a fluence of 40 J/cm², the speed of coverage can be more than 3 cm² per second. It is important to note that in order to increase the speed of hair removal, it is necessary to be able to increase the repetition rate (i.e. the rate at which single laser pulses can be placed on the skin one after another), and not the laser energy (or power) of a single laser pulse. Increasing the laser power of a single pulse above optimal levels would just cause damage to the skin at the irradiated spot. Therefore, for fast and safe hair treatments it is important that a device can deliver high average powers P_{ave} (calculated by multiplying a single spot laser energy with the repetition rate), and not the power P_{pulse} of a single pulse (calculated by dividing the single spot energy with the pulse duration). Typical pulse powers P_{pulse} are in the range of kilowatts, but the highest average power P_{ave} available in today's laser devices is 130 W.[20]

Generally, underarm, facial and bikini-line hair will be treated approximately every 4 to 6 weeks, only when new growth is present.

Forearms, back, chest and legs will be treated approximately every 2 months, only when new growth is present. According to clinical experience follicles treated in the anagen phase will shed hair 2 to 3 weeks after treatment.

Fig. 21. Before and after treatment of a large treated area.

CONCLUSIONS

Based on many considerations, the latest VSP (Variable Square Pulse) [2]. Nd: YAG lasers, combined with the computer controlled SOE technology are probably the optimal choice for performing safe and effective hair removal.

The Nd:YAG laser devices hold the most prominent position among all available laser sources due to its long wavelength of 1064 nm which in terms of absorption lies in an optical window that allows light at this wavelength to penetrate deep into the skin, while its absorption in the hair follicle is strong enough to destroy hair follicles.

Since it is clinically desirable to selectively treat the hair follicle without producing any injury to the surrounding tissue, laser energy is always delivered in single, short pulses. The pulse structure of the Variable Square Pulse (VSP) technology Nd:YAG laser systems is perfectly adjusted to the Tissue relaxation time (TRT) requirements of skin tissue. It ensures that the pulse width is optimized to the particular TRT's of the epidermis and the hair follicles.

Due to random laser light scattering, laser beam spot size considerations are important. Our study shows that for most cases the best spot size for hair removal is between 6 and 9 mm with a top hat laser beam profile. However, for the deepest hair follicles one must use larger spot sizes, in extreme cases up to 20 mm.

With today's request for speed and precision a scanner is a must. Advanced scanners, such as the Fotona S-11, utilize top-hat distribution technology to minimize hot spots in the scanning pattern and allows users to select a small spot size (3 mm) for shallower skin rejuvenation treatments, and medium spot sizes (6mm and 9mm) that are capable of penetrating deep enough to ensure effective hair removal treatments while maximizing patient safety and comfort.

In conclusion, the advantages of the VSP Nd:YAG lasers are numerous:

a) The appropriate wavelength with low absorption in epidermis and deep penetration down to the hair follicles.

b) The possibility to treat all skin types by sparing the epidermis.

c) The capability of generating appropriately high fluences at sufficiently short pulse durations in order to be able to treat thinner and/or lighter hair.

d) The capability of delivering top-hat beam profiles.

e) The most advanced VSP laser technology that can deliver high energies, high pulse powers and average laser powers in the same device.

f) The largest range of spot sizes to adjust the depth of treatment to the particular skin type and position on the body.

g) The safest and fastest skin coverage with computer controlled SOE scanners.

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