Thermokinetic Selectivity – A New, Highly Effective Method for Permanent Hair Removal: Experience with the LPIR Alexandrite Laser

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Pathological or cosmetically distressing facial and body hair is a problem for many people. In addition to the classic methods for hair removal such as shaving, wax and needle electrolysis, various laser systems, as well as incoherent light, have been available for several years to treat bothersome hair. In this context, laser epilation developed as an alternative to the known method of needle electrolysis. The latter process, for example, usually requires a treatment period of several years to remove hairs from the legs since every follicle must be treated several times on an individual basis. A risk of inflammation, infection and scarring in the area being treated is associated with this procedure.

Certainly the most widely used system for laser epilation is the ruby laser. Different systems with pulse lengths in "free running mode" that lie between 0.8 and 3 milliseconds are being used. The main indication for using the ruby laser still remains the very controversial treatment of benign, pigmented skin lesions and the removal of tattoos. Through adaptation of the equipment and the use of special applicators, the indication of laser epilation was also added. Because of certain physical characteristics and the tissue/beam interaction, the ruby laser with a pulse length of 1 millisecond cannot be described as ideal for the destruction of the hair follicle. The penetration depth of ruby light, which works at 694 nanometers, and the undesirable effects on the epidermis (pain, burns, blister formation – "Nicholski effect") meant that this equipment appeared to be less than optimal in the opinion of experienced laser users. The search for more suitable equipment – if necessary even a different principle of action – could no longer be postponed.

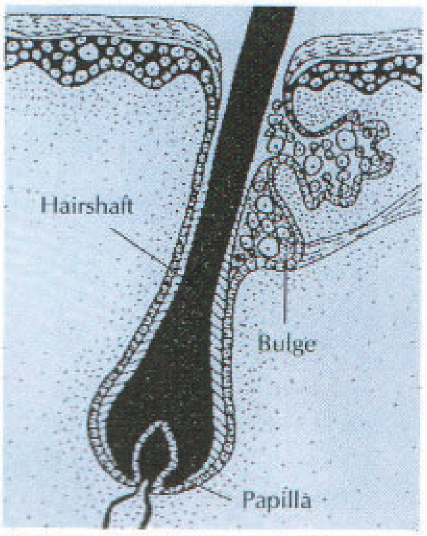

Fig. 1: A schematic representation of the hair follicle

Cynosure has developed a long-pulse, infrared alexandrite laser with a wavelength of 755 nanometers, which functions at impulse times of up to 20 milliseconds and employs the principle of thermokinetic selectivity. Many patients have been treated during the past four months using the only such laser currently available throughout Europe; some of them received follow-up treatment as part of a study (the results of the studies that are still in progress will be compiled and published).

Because of the extremely good results and positive patient acceptance, both during and after treatment, several

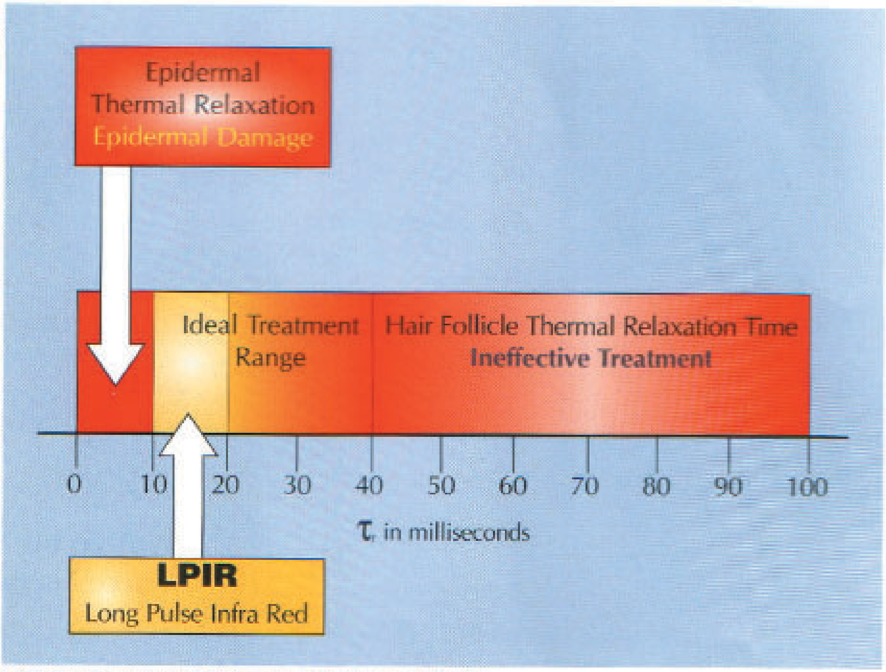

Fig. 2: Ideal treatment range for laser epilation

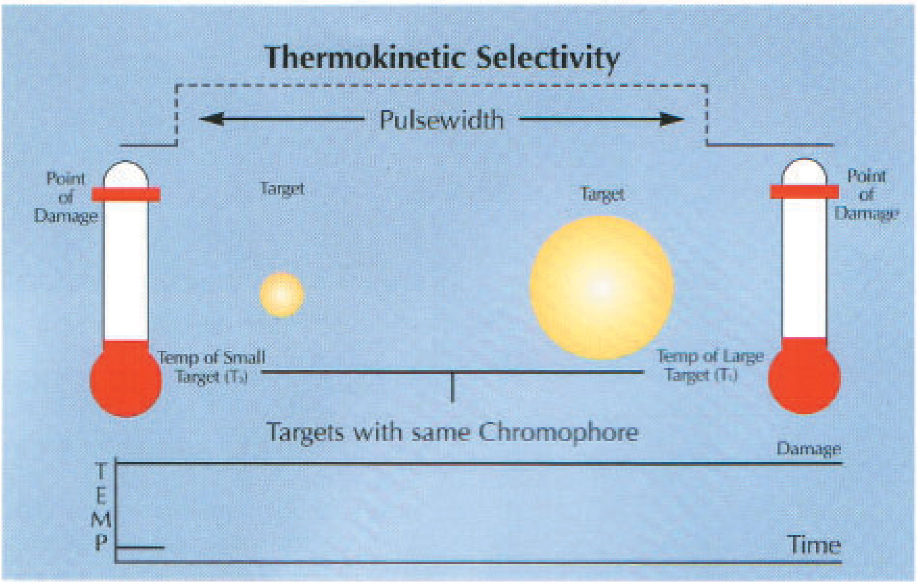

Fig. 3a: Through careful selection of the pulse duration and energy, the laser heats large targets in such a manner that they are destroyed while smaller structures of the same chromophore are merely warmed. This is the principle of thermokinetic selectivity. The diagram represents the status before the laser is applied. Both potential targets have the same temperature.

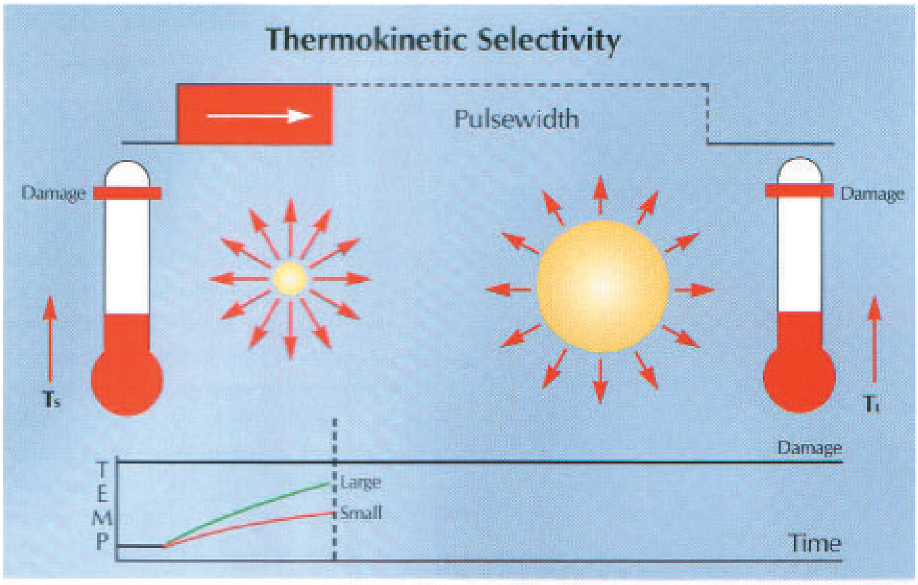

Fig. 3b: During the laser pulse the energy from both targets is absorbed. In varying degrees, both targets again radiate heat while the temperature continues to rise. Because of the more favorable surface area to volume ratio of the smaller target, it can more effectively distribute the energy to the surroundings than a large target with an unfavorable surface area to volume ratio. Therefore, the temperature in smaller target objects increases more slowly than in the larger structure.

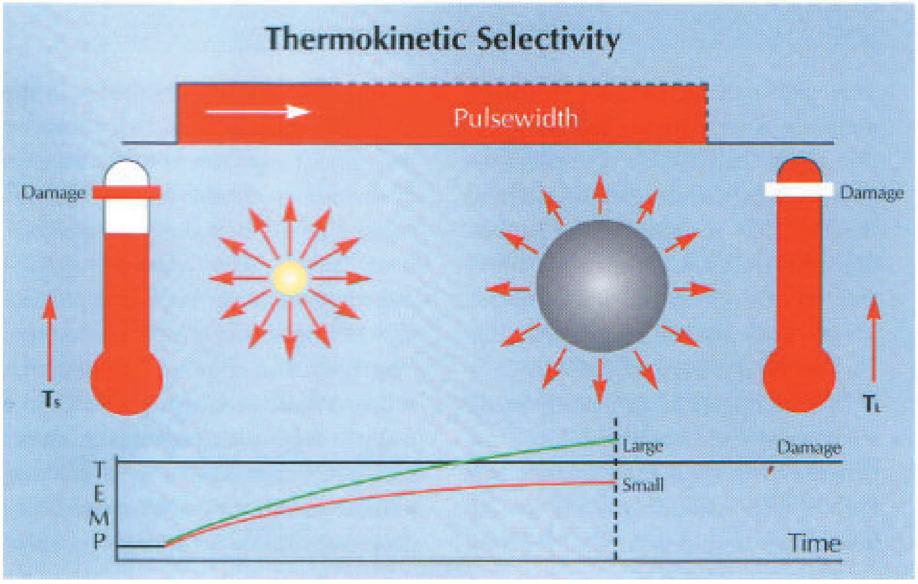

Fig. 3c: With continued pulse duration, the smaller target reaches its temperature plateau sooner and does not heat up as rapidly as the large target overall. In order to protect the small structure and damage the large one, the time (pulse length) during which sufficient energy is introduced must be long enough.

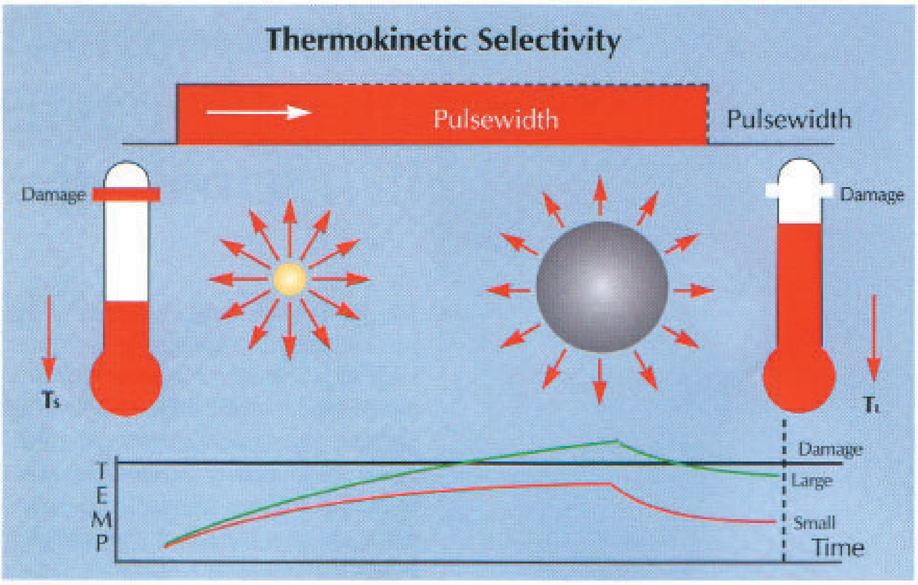

Fig. 3d: When the laser pulse has ended, both structures cool. As a result of this procedure, the larger structure has been damaged, the smaller one has not been damaged.

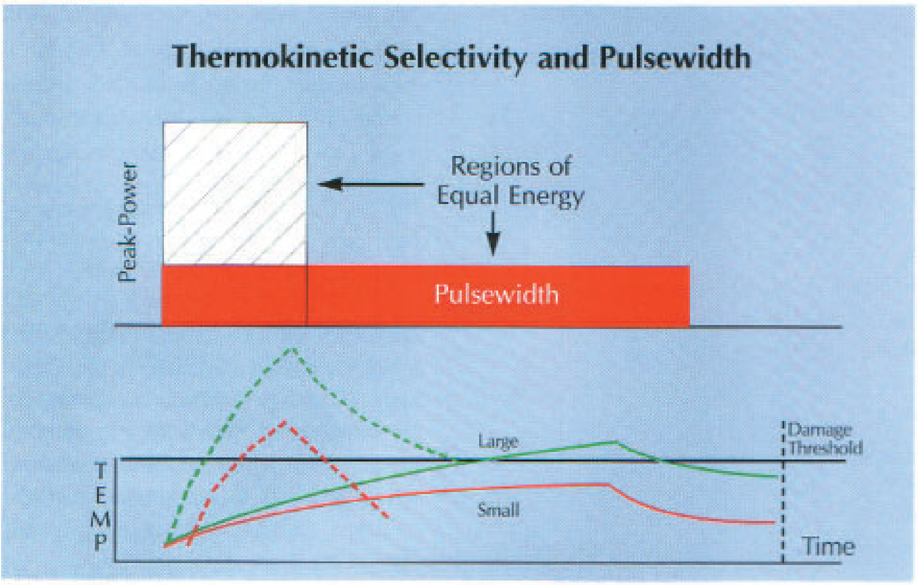

Fig. 3e: This diagram illustrates the difference between lasers that deliver the same energy dose, but do so during different pulse widths. During shorter pulse lengths, the peak energy must be clearly higher in order to attain a defined energy dose in the target structure. However, a higher energy will necessarily result in a clearly elevated temperature and will, therefore, damage both large and small structures in a similar manner.

basic principals and preliminary results will be presented below.

Manner of Action

"Thermokinetic Selectivity" or "the Thick Perspire Sooner than the Thin" (Modification of Allen's Rule)

Ideally, the pulse length must lie between the thermal relaxation time of the epidermis (between 3-10 milliseconds) and that of the hair follicle (Grossman, et al, 1996).

The objective of all laser epilation methods is the irreversible destruction of the hair follicle. For this purpose, other histologically defined structures, in addition to the papilla, that are significant in the regeneration and regulation of the hair follicle's growth may also be considered (Fig. 1). The total energy of the laser light (755 nanometers in this case) should selectively be absorbed by the melanin of the hair shaft and the hair bulb while preferably little or no absorption should occur in the structures of the surrounding skin or in the area of the blood vessels that comprise the dermal capillary system. Because of the energy uptake and the thermal heating of the hair shaft, those structures named above that are located directly next to the hair shaft are ideally destroyed. The problem and challenge posed to the development of a modern laser was the possibility of using energy to damage a large structure while simultaneously protecting smaller structures of the same chromophore that lie above it.

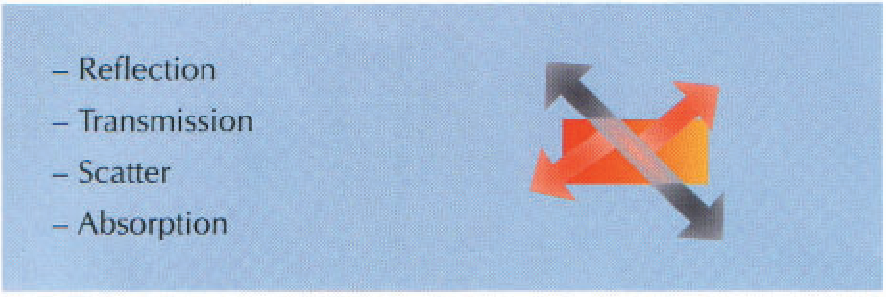

Fig. 4: Laser-tissue interaction

Absorption Coefficient at 755 nm: 28 cm^{1}
at 694 nm: 47 cm^{1}

$$(XI = \frac{1 - e^{-\alpha} 755 \cdot x}{1 - e^{-\alpha} 694 \cdot x} \qquad x = 0{,}1$$

(Epidermal/ dermal transitional zone)

Fig. 5: Formula

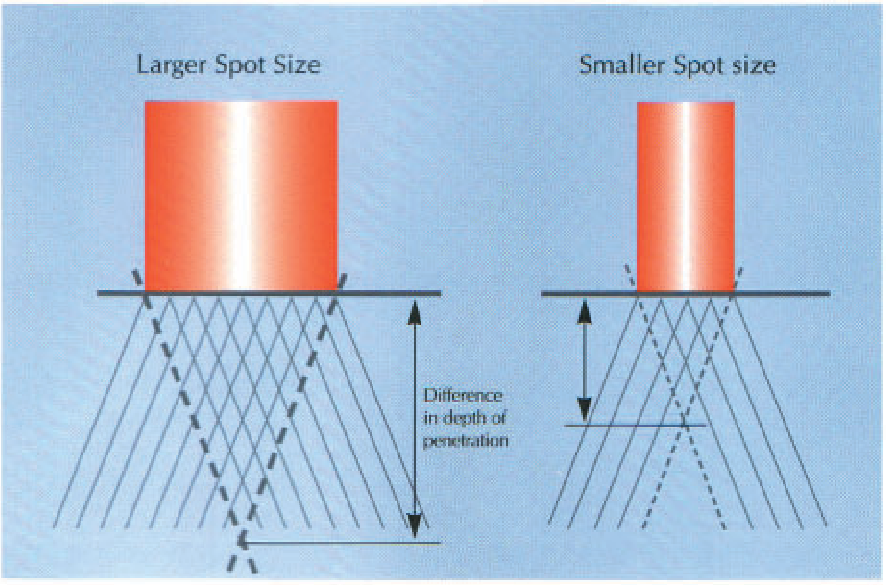

Fig. 6: Focus-dependent depth of penetration

Selective Photothermolysis – Thermokinetic Selectivity

The very well-known principle of *selective photothermolysis* means attaining a destruction of the target through an appropriate selection of the wavelength, the energy and the pulse length, while being mindful of the target cell's relaxation time and, as far as possible, protecting the surrounding tissue (i.e., treatment of tattoos). This can become problematic when the target has the same chromophore as the surrounding tissue or anatomical structures. The LPIR (long-pulse infrared) alexandrite laser uses a different approach and exploits the principle of *thermokinetic selectivity*. Because of the unfavorable volume-to-surface area ratio, target structures of large volume (e.g., hair) are not as capable of radiating the absorbed energy (heat) through their relatively small surface area and transmitting it onward into the surroundings as small volume structures of the same chromophore are capable of doing. After an appropriate time of exposure (pulse length), this results in a heating of the target structure and finally to a thermal destruction of the directly neighboring structures (papilla, germinative cell layer, bulge area). Therefore, the duration of the impulse must logically be selected to lie above the thermal relaxation time of the epidermis and below the thermal relaxation time of the target cell. Hence, it follows that an impulse duration of 10-40 milliseconds should prove ideal to damage the hair follicle without causing any harm to the epidermis (See Fig. 2 and 3a-d). The long-pulse alexandrite laser with pulse lengths up to 20 milliseconds fulfills this prerequisite and thereby also the conditions for thermokinetic selectivity.

Energy Density and Depth of Penetration

Since a hair is not a static structure, rather a dynamic one, and the target structures are located at various depths of the dermis while passing through the anagen to telogen growth phases of the hair cycle, the absorbed energy at greater depths must still be sufficient to cause permanent damage. During this process, the light is especially weakened by reflection, absorption and scattering (Fig. 4). Additionally, the depth of penetration is a function of the wavelength. In contrast to the ruby laser at a wavelength of 694 nanometers, the light of the alexandrite laser at 755 nanometers has a 1-1.5 mm greater depth of penetration, approximately 33% greater. (Fig. 5). The focus size of the incoming laser light also plays a role here. A larger focus results in a higher cumulative energy density at a given depth (Fig. 6). The spot size for the LPIR at 1 cm^{2} is approximately 4 times larger than

Table

Hair Growth Table (Richards-Merhag-Table)

	Percentage of testing hairs **Telogen**	Percentage of growing hairs **Anagen**	Percentage of transition hairs in **Catagen**	Percentage of **Uncertain** growth stage	Duration of growth time in **Telogen**	Duration of growth time in **Anagen**	Number of follicles per square cm	The hairs daily rate of growth	Total number of follicles in the area	Approx. Depth of terminal anagen follicle
Head										
Scalp	13	85	1-2	1-2	3-4 months	2-6 years	350	0.35 mm		3-5 mm
Eyebrows	90	10			3 months	4-8 weeks		0.16 mm		2-2.5 mm
Ear	85	15			3 months	4-8 weeks				
Cheeks	30-50	50-70					880	0.32 mm		2-4 mm
Beard-Chin	20	70			10 weeks	1 year	500	0.38 mm		2-4 mm
Mustache Upper Lip	35	65			6 weeks	16 weeks	500			1-2.5 mm
Body										
Axillae	70	30			3 months	4 months	65	0.3 mm		3.5-4.5 mm
Trunk	NA	NA					70	0.3 mm	425,000	2-4.5 mm
Pupic Area	70	30			3 months	4 months	70			3.5-5 mm
Arms	80	20			18 weeks	13 weeks	80	0.3 mm	220,000	2-4.5 mm
Legs & Thighs	80	20			24 weeks	16 weeks	60	0.21 mm	370,000	2.5-4 mm
Breasts	70	30					65	0.35 mm		3-4.5 mm

for the ruby laser. Energies up to 40 joules/cm² can be attained with the LPIR. When taken together, the above-named factors affect a high energy density in the dermis. This is particularly necessary in the early anagen growth phase (during which permanent damage to the hair can ideally be realized) where the papilla and the germinative structures can be up to 4 mm below the surface of the skin. The depth varies depending on body location, as does

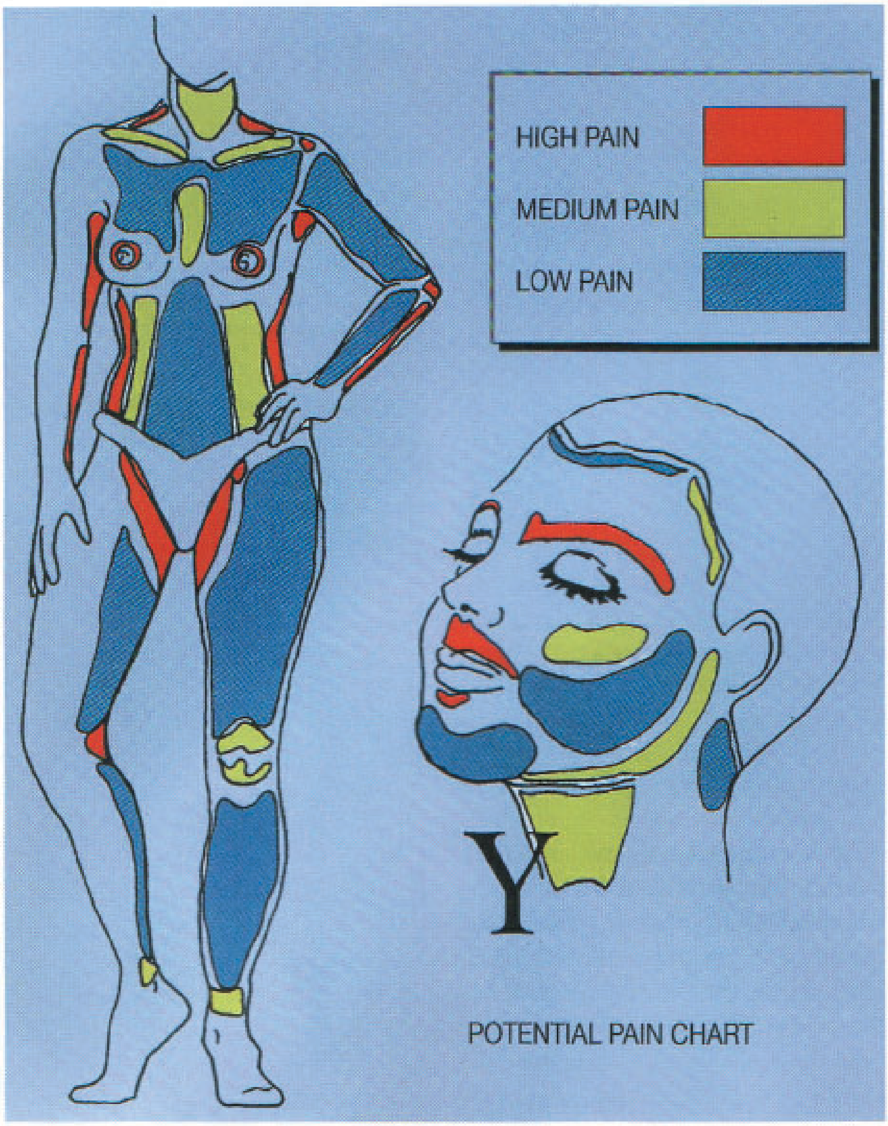

Fig. 7: Each patient experiences pain differently. Certain areas of the face and the body are more sensitive to pain than others. The diagram shows an approximate distribution of the areas with low, medium and high pain sensitivity.

the percentage ratio of anagen to telogen follicles (see Richards-Merhag Table). A glance at this table immediately shows why it is difficult to predict the success of treatment and the number of irreversibly damaged hair follicles. While approximately 70% of the hairs in the beard and chin regions are in anagen growth phase and are therefore in the optimum stage for laser treatment, only 20% of the hairs in the region of the legs and thighs meet this condition. Furthermore, the hairs in the leg region are in telogen growth phase for 24 weeks and conclusions concerning the effectiveness of the procedure and the need for additional treatment cannot be reasonably drawn until after this time period has elapsed.

Additional information is contained in the Richards-Merhag Table, indicating the average depth of the hair follicles in anagen growth phase according to location. At anagen follicle depths of up to 4 mm, it can also be seen where problems and therapeutic failures may be encountered when using laser systems such as the ruby laser which have an unfavorable effectiveness at greater depths.

Case Presentations and Treatment Parameters

During the past several months, more than 100 patients have been treated with the LPIR alexandrite laser. In addition to the face, the groin, lower leg and thigh, the axillary cavity as well as the breast and the back have been treated. On the day before treatment and in some instances also immediately before treatment, the region to be treated was thoroughly shaved and marked. In order to cool the epidermis and reduce the frequently reported prickly sensations experienced during treatment, ice-cooled sonography gel was uniformly applied at a thickness of approximately 1 mm. Only in the region of the upper lip was Emla salve regularly applied 1-2 hours before treatment (Fig. 7).

After treatment, some of the patients experienced reddening in the treated area that lasted between 3 and 24 hours. Blister formation and Nicholski phenomena have so far not been observed. In particular, hyperpigmentation or hypopigmentation and scar formation have so far not occurred postoperatively; a lasting dysesthesia – in the sense of hyperesthesias or hypoesthesias – has also not been reported. All patients were treated with a pulse duration of 20 milliseconds and an energy density between 18 and 30 joules/cm^2. The 10 mm probe with a 1 Hertz repetition frequency was used exclusively. Approximately 1 minute is required to treat hirsutism of the upper lip. After the operation, an antiseptic cream containing steroids was applied once and the patients were advised to gently cool the affected area in case of reddening or bothersome sensations.

In each instance, a patient initially received only a single treatment. The laser was applied to the entire area that

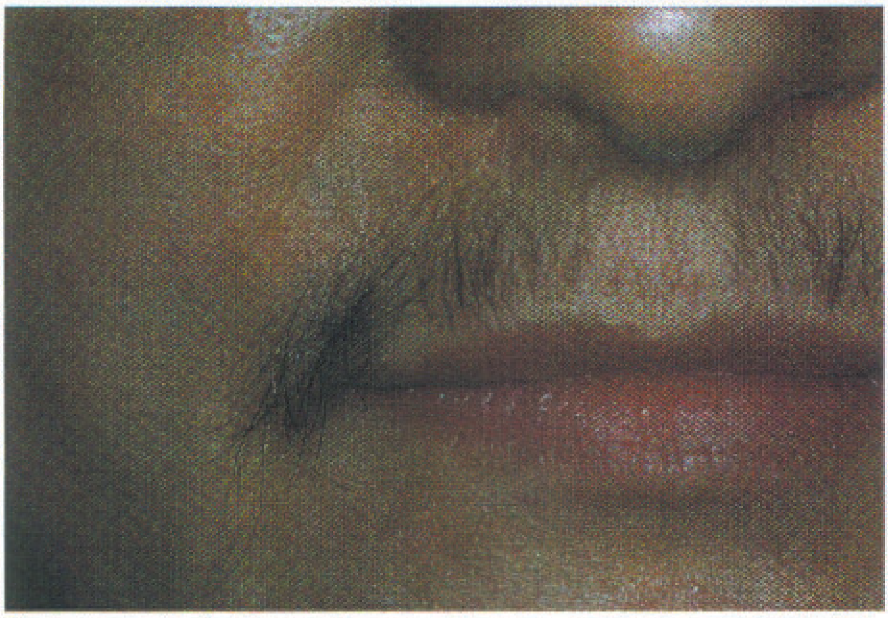

Fig. 8: A mustache of a 53 year old woman, which proved very disturbing emotionally. A single treatment with the LPIR laser resulted in an almost complete elimination of the hairs (observation period of 11 weeks).

required treatment in a single session and the patient was asked to return for follow-up evaluations of the findings in 2 and 14 days. So far the results can be characterized as extremely positive and promising. Most of the treatments in the facial area required 1-2 sessions; an interval of at least 6 weeks between treatments was observed. Even 3-4 months after a single treatment, only isolated hairs could be detected in many of the patients. Therefore, it can be assumed that the majority of the hair follicles have been destroyed by the procedure, at least in the facial area, based on a follow-up period of 4 months. Histological examinations that are, on average, conducted on day 2, day 14 and 6 weeks after treatment appear to confirm this. Final results including the histological findings will be published at the end of the study.

In summation, the LPIR alexandrite laser and the principle of photodynamic selectivity makes available new equipment for the treatment of hirsutism. After a 4 month trial, patient acceptance and the treatment's effectiveness can be described as decidedly good. In light of physical and anatomical considerations, this equipment must be described as being superior to the ruby laser in all points. The 10-15 treatment sessions that are typical with the ruby laser are unnecessary with this new equipment. It should also be mentioned that this equipment has been approved for the treatment of small to medium-size blood vessels (especially those between 0.6 and 3 mm) on the American market. The basic physical consideration is the same for this application. However, the treatment procedure is somewhat different. Treatments which we have so far conducted on 20 patients with spider veins and small reticular varices from 1-2 mm in size also appear to be quite promising.

Summary

This is the first report of a new laser (LPIR alexandrite laser; 755 nm) for permanent hair removal.

The laser functions by using the principle of thermokinetic selectivity. Large target structures store the absorbed heat energy longer than small structures of the same chromophore. The basic physical characteristics of the laser are explained in this article and initial results and successes are reported.

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