Coherent and incoherent intense light for hair removal has attracted an incredible amount of attention. This explosion of interest reflects a demand for more tolerable, practical, and effective epilation techniques. A variety of lasers and an intense pulsed light source are presently available for this purpose. One of the lasers currently being used is an Nd:YAG system at 1064 nm. This article reviews the Nd:YAG laser and its role in hair removal.

HISTORY

Neodymium is a faintly yellow, trivalent element classified in the rare earth family of metals. It was discovered in 1885 by C. A. von Welsbach and has an atomic number of 60, an atomic weight of 144.24, and many medical and industrial applications.

In 1961, neodymium was incorporated into a glass fiber and found to produce stimulated emission. Shortly thereafter, the ion (Nd³⁺) was used to dope crystals. Some of the host crystals have included CaF₂, CaWO₄, SrWO₄, SrMoO₄, Ca(NbO₄)₂, and Y₃Al₅O₁₂ (YAG). The latter crystal is commonly used today largely because of its efficiency. It has good optical quality and high thermal conductivity allowing high repetition rates.

The Nd:YAG laser at 1064 nm has been found to have many tissue effects. It suppresses collagen production in vitro and in vivo, ruptures melanosomes in laboratory animals causing epidermal depigmentation followed by gradual repigmentation and permanent leukotrichia, and it has been extensively used in urology, ophthalmology, neurosurgery, podiatry, dentistry, obstetrics/gynecology, gastroenterology, plastic surgery, and dermatology for a wide range of applications. Cutaneous targets include vascular lesions, tattoos and permanent cosmetics, deep pigmentation (e.g., nevus of Ota), nevomelanocytes, and hair follicles. An early publication on Nd:YAG laser hair removal was published in 1990. The continuous wave Nd:YAG laser was used to nonselectively destroy hair in urethral grafts. Many other lasers have been used for thermoablation of follicles. Though nonselective destruction is acceptable on unseen mucosal surfaces and small areas, the likelihood of a scar makes this technique unacceptable for large cutaneous surfaces. In order to achieve selective hair removal with this laser, thermal effects can be minimized by shortening the pulse duration. Lasers with this type of pulse-width have been studied by several different investigators.
FUNCTION

The Nd:YAG laser employs an yttriumaluminim-garnet crystal (Y₃Al₅O₁₂) in which Nd³⁺ replaces some of the aluminum atoms accounting for 0.5% to 1.5% of the total weight. When irradiated by an appropriate optical light source such as an arc lamp, a flash lamp, or a diode laser, the Nd:YAG crystal produces its strongest lasing emission at 1.064 µm. It is a four-level system with laser pulses occurring on transition between two intermediate energy levels (Fig. 1). It can be used in the Q-switched, long-pulse, and continuous modes. In the Q-switched mode, energy is stored in a closed cavity lasing medium until a maximum population inversion is reached. This can be achieved if a closed optical shutter is placed in the laser cavity so that laser pulses cannot occur until the shutter's polarization is changed. If the polarization is changed at the appropriate time, light is allowed to oscillate through the shutter and an ultra-high power pulse is delivered over a short pulse duration.⁶²,⁶³

Continuous wave Nd:YAG lasers are usually pumped by an arc lamp and actually produce quasi-continuous laser light at a very high repetition rate of roughly 20 kHz. The pulses are of 200 to 300 nanoseconds in duration.⁶³

RATIONALE FOR USING THE ND:YAG FOR LASER HAIR REMOVAL

There are several reasons for considering the Nd:YAG laser as a good choice for hair removal. A longer wavelength provides for better penetration. Because the deepest anagen hair bulbs are approximately 4 to 5 mm in depth, transmission to this depth is critical to achieve best results. Lasers of shorter wavelengths do not penetrate as deeply. Longer wavelength light is absorbed by water and therefore has diminished transmittance. A penetration window exists at around 1.0 µ. The Nd:YAG laser at 1.064 µ approximates the maximum penetrance (Fig. 2). Absorption by surrounding skin structures is an important factor. Optimally, one would want no absorption by any skin components except the target. Unfortunately, such a situation does not exist. The absorption spectrum, however, demonstrates that at 1.0 µ there is less relative absorption by cutaneous

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**Figure 1.** The Nd:YAG laser four-level system. Transition between two intermediate energy levels produces laser emission at 1064 nm.
chromophores than at any other wavelength (see Fig. 2). This feature not only enhances penetration, but it also reduces the risk of side effects. An important advantage of using 1064-nm Nd:YAG laser light is its relatively low clinical side-effect profile. A very low incidence of dyspigmentation and cutaneous textural change is noted in many publications.34, 36, 47, 48, 50, 51

Practicality of a laser hair removal system is also of prime importance. Patients often request treatment of large body sites such as the legs and back. A large beam size and quick repetition rate is therefore essential for efficiency. The Nd:YAG laser has the capability of being pulsed rapidly, up to thousands of pulses per second (depending on the pulse duration). The present common pulse repetition rate of 10 Hz balances speed with manageability. In addition, the 7- to 8-mm beam size that is currently available is well-suited for quick coverage of large surfaces.

**EPIDEMIOLOGY OF THE INTERESTED POPULATION**

Two main groups of individuals seek hair removal: those with increased hair in undesirable locations secondary to genetics or a medical condition, and those with hair that would be considered normal in distribution and density, but for emotional, social, or other reasons want the hair to be removed.

Those with truly increased hair number may be classified as having hirsutism or hypertrichosis. Hirsutism is defined as excess male pattern hair growth in a female (Fig. 3). It can vary from mild, with a few chin or upper lip hairs, to severe, with thick coarse hair on the beard, chest, back, abdomen, and extremities. It has been estimated that 9% to 15% of college-aged females have severe hirsutism.20, 49 The number of individuals with mild hirsutism who would be interested in hair removal is likely to be much higher. Hirsutism may be associated with an underlying endocrine disorder, an androgen-secreting tumor, heredity, or a medication. Evaluation and management of hirsutism are reviewed in several recent articles.8, 13, 27, 39, 43, 60, 66

Hypertrichosis may be defined as localized or generalized excess hair in a male or female (Fig. 4). It is difficult to determine the number of individuals affected with this condition as studies rarely address incidence. True hypertrichosis can be owing to a drug, internal malignancy, trauma, or genetics.9 The treatment of the underlying cause is clearly of great significance and may greatly decrease the hair
**Figure 3.** A hirsute female with male pattern hair growth of the chin.

**Figure 4.** The back of an 8-year-old girl with hypertrichosis lanuginosa congenita.
growth; however, those who have persistent hypertrichosis often request removal.

Individuals who have hair that is normal in distribution and density represent the largest group requesting hair removal. Females may request hair removal from the bikini area, axillae, legs, and face, whereas males may want epilation from the back, chest, upper arms, and face. Requests for hair removal in other areas are not uncommon.

HAIR STRUCTURE AND FUNCTION

The reader is referred to several articles and textbooks for a complete review of this subject, however, some points relevant to this discussion will be addressed in this section. The hair periodically cycles through three main stages: anagen, catagen, and telogen. During anagen, hair matrix cells are actively dividing, lengthening the hair shaft. It is, therefore, referred to as the "growing" stage. Anagen is normally subdivided into six stages, the first five are termed proanagen and are defined by the position of the hair shaft tip within the follicle (Fig. 5). The sixth stage is termed metanagen and begins when the hair tip is evident above the skin surface. Following a variable period of hair growth (depending on the body site), the "breakdown" or catagen stage begins. During this relatively brief stage, the lower follicular keratinocytes completely degenerate, and the hair papilla begins retracting toward the area of the bulge. Once the papilla reaches its final destination, the telogen or "resting" stage begins. The only portions of the pilosebaceous apparatus that are truly resting are the hair matrix and shaft, as their proliferation and growth cease. The remainder of the follicle continues its activity. At the end of telogen, upon appropriate cytokine stimulation, the hair bulb begins to descend with a new complement of matrix cells that ultimately produce a new hair. Anagen begins again and the cycle repeats itself periodically in this manner.

The pilosebaceous apparatus consists of multiple components (Fig. 6). Several pertinent features of the pilosebaceous apparatus can be identified. This figure shows a terminal hair with an average diameter of 60 to 80 µm. Vellus hairs are less than 40 µm in diameter and contain little melanin. The average anagen VI terminal hair is 4 to 5 mm in depth and 250 to 300 µm in diameter.

Figure 5. The hair cycle.
Important anatomic features include the hair papilla, which is surrounded by follicular keratinocytes forming the hair matrix. The hair papilla consists of fibroblast-like cells, collagen, blood vessels, nerves, and androgen receptors. The papilla dictates several characteristics of the hair. The hair matrix consists of follicular keratinocytes that actually produce the hair shaft itself. At the insertion of the arrector pili muscle is a region of pluripotential cells termed the area of the bulge. These cells probably replenish hair matrix germinative cells during the telogen phase. Many other structures can be identified in the Figure 6, but will not be discussed here.

THEORETICAL CONSIDERATIONS

In order to eliminate hair effectively, it is crucial to understand the specific areas of the follicle that need to be damaged. Many studies attest to the fact that the hair follicle is an incredibly resilient structure, regrowing after seemingly lethal injury. Oliver has published a series of interesting experiments on the hooded rat that showed that even after the removal of up to the entire lower third of the hooded rat vibrissae follicle, a new hair regrew. Supporting this observation is work by Reynolds and Jahoda, in which the removal of the lower third of a rat vibrissae follicle resulted in regrowth of a new vibrissae hair follicle. This was thought to be because of germinative epithelial cells inducing dermal sheath cells to form a new hair papilla, resulting in the formation of a new follicle. Their study also showed that cultured rat pelage hair papilla cells implanted into rodent foot pad skin grew hairs, implying that
undifferentiated nonfollicular epithelial germ cells could be induced to form a hair follicle; however, it has been shown that implanted follicles devoid of more than their lower third are unable to produce a hair. These studies combined suggest that the lower third of the follicle is the region that needs to be damaged in order to destroy the follicle. The structures in this area include the hair papilla and germinative cells. If either element remains, one can apparently induce its counterpart to reform.

It has generally been assumed that the follicular germinative epithelial cells are located only in the hair bulb. Matrix cells indeed do have stem cell characteristics because they are relatively undifferentiated and normally slow cycling, but they also proliferate very rapidly during anagen. More recent studies give support to the thought that the main pool of germ cells may not be located in the hair bulb region at all. In fact, several studies suggest the location for the chief source of follicular stem cells to be in the area of the bulge. These cells are a subpopulation of the outer root sheath and possess many typical stem cell features. They are relatively undifferentiated and slow-cycling, but able to proliferate rapidly on demand. In addition, they are located in a rather well-protected, nourished, and innervated location, and are found at the most inferior portion of the permanent follicle, the site to which the dermal papilla retracts during telogen, at the insertion of the arrector pili muscle. Destroying stem cells in this region and the remainder of the deeper

Figure 6. See legend on opposite page
follicle would require damage to slightly more than the lower third of the follicle. If this is done, a hair should not regrow.

**REQUIREMENTS FOR LASER HAIR REMOVAL**

Several components are necessary to selectively damage a hair follicle with a laser: a chromophore in the follicle (preferably specific for the follicle alone), a laser light that targets the chromophore, and appropriate laser parameters that limit damage only to the follicle. These requirements are discussed in the following sections.

**Chromophore**

Melanin is the innate cutaneous chromophore used most commonly as a target for hair removal lasers and light sources (Table 1). The advantage of choosing melanin as a target is that it is already present in the hair follicle and shaft; however, there are several disadvantages. One disadvantage is that not all hair has melanin. White hair has no melanin and blonde or red hair has phaeomelanin, which is a relatively weak absorber of light. Therefore, if melanin is the target, only dark hair would be expected to respond well. In addition, this pigment is found not only in the hair follicle, but in the epidermis as well. Light must initially pass through the epidermis in order to get to the deeper hair follicle and is therefore absorbed superficially first. This has several consequences. Absorption of light in the epidermis results in adverse effects such as vesiculation, crusting, burns, and dyspigmentation. In addition, the more laser light absorbed in the epidermis, the less light available for damaging the follicle. As a result, higher fluences are required for effectiveness, and higher fluences can lead to more adverse effects. The best candidates for melanin-seeking laser systems are individuals with dark hair and light-colored skin. Using these systems to treat an individual with darker skin, especially types V and VI, would be expected to have many adverse effects unless the fluence is significantly reduced.

Another alternative to using melanin as a chromophore is to use an exogenous agent. An exogenous agent such as topical aminolevulinic acid (ALA) is used in photodynamic therapy for hair removal. This is also the idea behind the topical suspension assisted Qswitched Nd:YAG laser hair removal system (TSALHR [ThermoLase, San Diego, CAD. The advantage of these techniques is a strong absorbing chromophore that is not found in the surrounding structures. Therefore, if the chromophore can be well dispersed in the follicle, a totally selective destruction could be achieved. The challenge is good biodistribution of the chromophore.

ALA is a porphyrin precursor. When ALA is applied to the skin surface under occlusion, it can eventually diffuse into the hair follicle. Once absorbed in follicular keratinocytes, it is metabolized to protoporphyrin IX, which has several absorption peaks, one of which is 630 nm. Irradiation by incoherent light at this wavelength induces singlet oxygen, which subsequently oxidizes and damages follicular cells and proteins. Subsequent hair reduction depends on the severity of cellular damage.

The chromophore used in TSALHR is a carbon particle suspended in mineral oil. Carbon was chosen for its strong absorption characteristics, its safety, and its availability. As can be seen in Figure 2, the absorption coefficient of carbon at 1064 nm is thousands of times greater than melanin. It is safe because all living tissue is formed mostly from hydrocarbons. In addition, carbon is the fourth most abundant element on earth so it is easily acquired.

Carbon comes in all shapes and sizes, from large crystalline sheets of graphite to small nanometer-sized geodesic structures termed
fullerenes. Clearly, small particles are required to have a chance of penetrating down the hair follicle. Therefore, nanometer to micron diameter particles have been used in TSALHR. Originally, 10-µm graphite particles were used, but the size has subsequently been decreased to 100 nm carbon black to enhance penetration and therefore results. Different agents continue to be tested in order to find the optimal topical.

**Wavelength**

The optimum laser wavelength for hair removal would be deep penetrating, not well absorbed by surrounding structures, but strongly absorbed by the follicular chromophore. Penetration is intimately associated with and inversely proportional to absorption by the surrounding skin. It is clear that the more light absorbed by the skin, the less energy available for penetration. Therefore, a wavelength of approximately 1 µm should have the best penetration (see Fig. 2). Indeed, this is evident both in vitro and in vivo.

An in vitro experiment (Thermolase, personal communication, ThermoLase Corporation, August, 1996) demonstrated that 1064 nm laser light penetrates at least 4 mm through porcine tissue and still retains enough energy to vaporize carbon (Fig. 7). Several 2-mm slabs of porcine tissue were stacked upon each other and carbon was placed on the surface, at 2 mm, 4 mm, and 6 mm. Exposure to 1064 nm Q-switched laser light demonstrated that carbon could be vaporized at the surface and at the 2-mm and 4-mm depths. Carbon was not affected at 6 mm in this study.

Another experiment done in vivo (Thermolase, personal communication, ThermoLase Corporation, October, 1996) demonstrates the relative transmission of several different laser wavelengths (Fig. 8). The earlobe and first interdigital fold served as sites for laser exposure. A detector was placed on the opposite side and the difference between incident and transmitted light was calculated. Light from the Q-switched Nd:YAG laser at 1064 nm had greater transmission than the shorter wavelengths tested as predicted by the absorption curves. This indicates that higher energy will be delivered to the hair bulb if 1064-nm light is used. Although longer wavelengths theoretically should penetrate better, absorption by water prevents this from occurring.

**Pulse Duration**

The pulse duration of an instrument is a critical feature for precise follicular damage. Most systems use a relatively long pulsewidth in the 1- to 3-msec range. The exposure time was chosen according to the theory of selective photothermolysis. The approximate thermal relaxation time (TRT) in seconds is equal to

![Figure 7. In vitro experiment demonstrating the depth of effective penetration of the Q-switched Nd:YAG laser.](image)
the target diameter squared in millimeters (TRT[sec]≈D2[mm]). If an average follicle is 250 µm, then the TRT is roughly 60 msec. Therefore, the pulse-width should be equal to or slightly less than this time. Because most systems target melanin and this pigment is located in the epidermis as well as the follicle, to avoid surface injury, the TRT of the epidermis must also be considered. If the average epidermis is roughly 100 µ in depth, the corresponding TRT is close to 10 msec. Therefore, to decrease superficial epidermal injury and continue to maintain efficacy for hair removal, a pulse-width between 10 msec and 60 msec should theoretically be used. This pulse-width allows for both selective photothermal injury to the hair follicle and effective cooling of the epidermis, preventing superficial damage. Thermal effect alone results from a millisecond pulse duration.

Is it possible to cause enough injury to damage a hair follicle by using an ultrashort pulse? It has been shown that hair removal can be accomplished with such a system. The SoftLight system (ThermoLase, San Diego, CA), MedLite 4 (Continuum Biomedical, Dublin, CA), and other Q-switched Nd:YAG lasers have pulse widths in the nanosecond range. Each has been demonstrated to remove hair for a variable time period. The mechanism of action is thought to be because of vaporization of the chromophore resulting in huge shock waves that damage tissue. It may be that rapidly dividing cells (i.e., hair matrix keratinocytes) are more susceptible to the mechanical disruption, which results in a delayed regrowth.

The SoftLight system is thought to work in the following manner. Immediately after Q-switched 1064-nm laser exposure, carbon is heated to its vaporization temperature of about 3700° C. Vaporization leads to a huge volume expansion with resultant supersonic proliferation of high pressure waves of at least 100 atmospheres (Fig. 9). These shock waves, in turn, produce mechanical damage, as well as the development of heat. It is not certain how much mechanical and heat energy produced by
this mechanism is required for destruction of a hair follicle; however, it is histologically evident that follicular damage does occur following laser exposure, resulting in a clinical delay of hair regrowth. Depending on the position and amount of the chromophore, as well as the energy administered, it may be possible to irreversibly damage a hair follicle with a Q-switched instrument.

**Beam Size and Repetition Rate**

The beam size of an instrument is important for procedure speed as well as transmission. Clearly, speed is essential for treating large areas such as the back or legs in a relatively brief period. A large beam size coupled with a rapid repetition rate is optimum. The Q-switched Nd:YAG systems each have 4- to 8-mm beam sizes and a 10 Hz repetition rate. Transmission of laser light to the hair bulb is also essential for deep follicular damage, and as the beam size increases, so does transmission (see Fig. 8). A simple explanation of this effect is shown in Figure 10. A narrow beam begins to scatter as it enters the skin, rapidly losing energy. If a wide beam is envisioned as a coalition of narrow beams, scattering again occurs on contact with the skin surface; however, scattering is greater toward the beam center, effectively increasing laser energy at any given depth. This effect levels off at about

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**Figure 9.** Demonstration of the photomechanical effect of the Q-switched Nd:YAG laser and carbon. A, Two glass slides with carbon between them. B, Shattering glass slides during laser exposure at 2.5 J/cm², 17 nsec, 1064 nm. C, Postlaser exposure.

**Figure 10.** The effect of beam diameter on effective laser penetration. At the same fluence, a wide beam delivers higher energy at any given depth. A, Narrow beam. B, Wide beam.
10 mm and minimal additional benefit is realized if one increases the diameter beyond that. This finding is also supported by other investigators.35

**CLINICAL STUDIES**

**Review**

Many clinical studies have involved use of the Q-switched Nd:YAG laser. Several of these studies are discussed in this section.

Hair removal using a continuous mode Nd:YAG laser was described in 1990.21 Hair-bearing urethral grafts were epilated by using a 40-watt, 1064-nm light at up to 2-second increments. The beam size was 1 to 2 mm, and the 600-mm fiber was held either in direct contact with the mucosal surface or noncontact up to 0.5 cm away. The total energy used for each treatment was 3,000 to 6,000 J. Two to three treatments were performed on three male patients resulting in nearly complete epilation at a 15- to 18-month follow-up. No functional scarring was noted in this study, though apparently significant nonselective thermal damage was done to destroy the follicles.

Several studies have examined the Q-switched Nd:YAG laser at 1064 nm with and without a topical chromophore. Nanni and Alster51 performed four different treatment variations on 12 subjects in a variety of body areas. One site was only wax epilated, another laser alone, and a third site was waxed then laser. The last area was waxed and a topical carbon suspension applied before lasing. Each subject was treated once and followed at 1, 3, and 6 months. At 3 months the wax epilated site had a mean regrowth of 102.2%, the laser alone site 86.3%, the waxlaser site 85.2%, and the wax-carbon-laser site 79.1%. At 6 months essentially all hair had regrown in all sites. The authors concluded that all laser-treated sites demonstrated a decrease in hair density after one treatment for up to 6 months compared to the wax epilated control. It was suggested that the exogenous chromophore may be especially helpful when treating lighter hair.

The same authors retrospectively reviewed charts and compared three different lasers for hair removal.50 Patients treated with the long-pulse ruby (Epilaser, Palomar, Lexington, MA), long-pulse alexandrite (LPIR, Cynosure, Chelmsford, MA), and the TSALHR (SoftLight, ThermoLase, San Diego, CA) were included. Each patient had undergone three or more laser treatments. Evaluations were based on chart reviews, photographic analysis, and patient questionnaires. Results indicated that multiple laser treatments were more effective in reducing hair growth with each system. After treatment discontinuation, the alexandrite and ruby lasers were shown to produce a greater hair reduction than TSALHR, but side effects and complications were lowest with the TSALHR. Hypopigmentation was most common with the ruby laser, and hypo- and hyperpigmentation occurred with the alexandrite along with crusting and erosion in darker skin types.

Kilmer et al34 compared another Q-switched Nd:YAG laser (Polytec PI, Auburn, MA) with the ruby (Epilaser, Palomar, Lexington, MA) and alexandrite (LPIR, Cynosure, Chelmsford, MA) systems. Up to three treatments were administered to twenty test subjects. Each of the three lasers was used to treat one test quadrant. The fourth quadrant was not treated and served as a control. Evaluation was done subjectively by the patient and physician at each follow-up visit, which corresponded to the time of first hair regrowth. After the first treatment, hair reduction was 60%, 60%, and 40% for the ruby, alexandrite, and Nd:YAG respectively. The second treatment resulted in a higher percentage reduction of 70%, 80%, and 60%. Blistering and dyspigmentation was noted in darker skin types with the two shorter wavelengths. The Nd:YAG laser had the least risk of dyspigmentation even though epidermal disruption occurred at the high fluences (10 J/cm2) used.

Several studies have been done using the TSALHR (SoftLight, ThermoLase, San Diego, CA). The original clinical study involved 64 subjects, aged 21 to 74. Racial evaluation revealed 59 Caucasians, 3 Hispanics, and 2 African-Americans. Participants were treated in two of the following four sites: upper lip, chin, preauricular region, and neck. Treatment was done with a Q-switched Nd:YAG laser operating at a wavelength of 1064 nm and a fluence of 2 to 3 J/cm2 in a 3 X 6mm beam. A
Continuum Biomedical (MedLite 1, Dublin, CA) or Derma-Lase (DLY-l, Hopkinton, MA) laser was used for treatment. One treatment was done at the initial visit with follow-up at 4 and 12 weeks. Evaluations were done by both physician and subjects at the follow-up visits. The mean percentages of overall hair reduction are shown in Figure 11. Essentially, 50% to 60% hair reduction was noted by physicians at the 12-week visit. Figure 12 shows the appearance of an individual with type V skin at baseline and 12 weeks after a single treatment. Note a significant decrease in hair density with minimal transient hyperpigmentation, which resolved completely at 16 weeks. This was the lone subject who experienced hyperpigmentation in this study. One patient had a significant reduction of white hair in the area of treatment 12 weeks after a single treatment (Fig. 13). Side effects consisted of transient erythema, edema, occasional petechiae, and rare hyperpigmentation.

A follow-up clinical study was done shortly after this to determine the effectiveness of a new Q-switched Nd:YAG laser developed for ThermoLase Corporation (Lorad, Danbury, CN).26 The main difference in the new instrument was a larger beam size of 7 mm to enhance speed and penetration. In addition, a more uniform beam energy distribution decreased "hot spots," minimizing side-effects such as petechiae. All other laser parameters and study procedures remained the same; however, the axilla was added as an additional site (Fig. 14). Both physician and subjects assessed the areas of treatment at 12 weeks. Physician
assessments ranged from 30% to 65% and subjects from 10% to 44% depending on the body site. The chin appeared to be the area most resistant to treatment and the upper lip and cheek the most responsive.

In an effort to enhance procedure results, wax epilation was introduced into TSALHR. The intention was to remove the hair shaft, opening a 70- to 80-µm space for carbon to penetrate, therefore improving the chromophore distribution. Thirty-five subjects were treated once in 83 anatomic sites including the upper lip, cheek, chin, back, bikini area, axilla, neck, navel, and abdomen. The sites were prepared with a mild cleanser, then wax-epilated, coated with the carbon lotion, and lased. The 7-mm beam size instrument was used at 2.5 to 3.0 J/cm² and 1064 nm (Lorad, Danbury, CN). Follow-up was at 4, 12, and 24 weeks. The average percent hair reduction is summarized in Figure 15. All side effects were transient.

Long-term hair reduction and the effect of multiple treatments remained to be examined. If one treatment could achieve a 50% reduction, multiple treatments would empirically give better results. A subsequent study was therefore conducted, which involved six treatments at monthly intervals and a 52-week follow-up. Forty-eight volunteers, aged 20 to 82, with type II–IV skin, were treated with the TSALHR. Treatment was virtually the same as in the initial study, but the instrument with the 7-mm beam was used (Lorad, Danbury, CN). The sites of treatment were the upper lip and chin. Using the philtrum as a vertical dividing line, one half was treated once and the other half treated 4 to 6 times at monthly intervals. Follow-up was monthly for 6 months, then at week 32 and 52 (Fig. 16). A reduction of approximately 20% was noted 52 weeks after a single treatment by physician assessment. Multiple treatments produced a slightly greater reduction, though it was not statistically significant. Figure 17 and 18 show clinical results in a subject treated in this study. At 16 weeks, the singletreatment side of the upper lip (subject’s right) showed a significant hair reductio

Figure 12. Patient with skin type V. A, The preauricular area before treatment. B, Twelve weeks after one treatment.
whereas the multiple-treatment side (subject's left) essentially had no visible hair (Fig. 17). The 52-week photograph still shows a significant hair reduction on both sides. The chin, shown at 52 weeks, has a marked decrease in hair density bilaterally (Fig. 18). Side effects were transient erythema and edema, which usually lasted less than 1 hour. No dyspigmentation was seen in any patient in this study.

Discussion

A variety of points may emerge from analysis of the foregoing studies, effectiveness being perhaps the most obvious. Several authors have compared the Q-switched Nd:YAG laser with the ruby and alex and rite lasers. In each of the studies, the latter instruments have apparently produced greater hair reduction than the Nd:YAG laser. If true, this may occur for the following reasons. The Nd:YAG laser wavelength of 1064 nm is more weakly absorbed by the innate target melanin than are the other instruments. Lower absorption translates into less energy available to damage the follicle; therefore, lower absorbing wavelengths would be expected to reduce hair loss. The exogenous chromophore carbon has been
Figure 14. The mean percent hair reduction 12 weeks after one treatment. A, Subject assessment. B, Physician assessment. Light-tone bar number of subjects; dark-tone bar percentage of average reduction.

Figure 15. The mean percent hair reduction after one treatment. The average hair reduction is shown at 24 weeks. Solid symbol average; shaded symbol subjects reporting.
used in the ThermoLase system for this very reason. According to Nanni and Alster,\textsuperscript{51} follicular incorporation of this strongly absorbing element would be expected to significantly improve results. It has been suggested that follicular incorporation of carbon may also be useful in treating hair with little or no pigment.

Larger differences in epilation with carbonlase versus lase alone may be achieved with optimal follicular chromophore distribution. Many approaches to improving distribution have been examined including smaller carbon particles (nanometer vs. micron size), a variety of concentrations, different application or skin preparation techniques, more penetrating vehicles, and increasing the "receptacle" size by wax epilation. Unfortunately, these methods have only marginally increased follicular carbon. It may be that a better approach would be the use of a solution as opposed to a suspension. The former has a much greater chance of diffusion into the follicle and, therefore, enhanced results after lasing. If such a solution is feasible, effectiveness would be expected to be as good or better with the Nd:YAG than with other laser systems.

A fluence increase from 2.5 to 10 J / cm\textsuperscript{2} with the Q-switched Nd:YAG laser apparently does not improve effectiveness. Results reported by Kilmer et al\textsuperscript{34} using the high fluence Nd:YAG were not significantly different from those of other authors who employed the low fluence instrument\textsuperscript{26, 47, 48, 50, 51}. Changing other laser parameters may have a greater influence. For instance, increasing the pulse duration from the nanosecond to millisecond range could produce enough follicular thermal effect for destruction, especially in the presence of a potent target. In addition, the fluence could be increased markedly and the skin cooled effectively resulting in an effective instrument with very few side effects.

Adverse events with the low fluence Qswitched Nd:YAG laser are consistently reported to be lower than any other hair removal light source. The low fluence contributes to this small incidence of complications, but poor melanin absorption probably is the biggest factor. Because of poor melanin absorption, 1064-nm light passes harmlessly through tissue, rarely producing side effects. Mild erythema and edema occur, but usually resolve within an hour. No permanent cutaneous changes have been reported in any of the studies to date. Though discussion has suggested that infection, scarring, and tattooing are possible with this instrument, none of these findings has been noted in hundreds of thousands of treatments. High fluence Nd:YAG lasers produce epidermal disruption and therefore potentially more side effects than the lower fluence models; however, studies indicate that the incidence is still less than with other hair removal light sources.

It has been suggested that multiple treatments are more effective than a single treat-
Figure 17. The perioral area of a treated subject. A, Before treatment. B, Sixteen weeks after the initiation of treatment. C, Fifty-two weeks after the initiation of treatment.
ment. If it is true that only anagen hairs are affected by laser, even if 100% anagen hairs are destroyed, one treatment would not be expected to reduce clinical hair density by 100%. For instance, less than 50% of hairs are in anagen at any one time on the leg of a person. If a laser treatment is administered and destroys 100% of those anagen hairs, 50% of the follicles will be destroyed and 50% will produce a new hair. Anagen hairs will remain for 2 to 6 weeks then fall out, whereas telogen hairs will ultimately cycle back into anagen; however, there will always be some hairs in anagen and some in telogen. Therefore, even if 100% of anagen hairs are destroyed after each treatment, only a percentage of total hairs will be eradicated. The same holds true for each successive treatment; therefore, multiple treatments are required in the best case scenario. In practice, less than 100% anagen hairs are destroyed in any given treatment as no medical treatment is 100% effective. In addition, the most susceptible hairs are probably only those in early anagen, which represents a smaller number than the total anagen follicles. Therefore, a smaller percentage of hairs would...
be affected and more treatments would be required for a significant decrease in hair density. Laser effects on hair are many. One of these observed effects is a laser-induced telogen. Soon after lasing, actively growing hairs shut down and enter a resting phase (see the section on Histology). If it is true that anagen hairs are most affected by lasing, this finding may have great significance, Because the normal cycle of hairs on the body is completely asynchronous, multiple treatments are required to hit every hair in early anagen. If lasing induces a telogen in most hairs, a synchrony would be produced and more of the hairs would enter anagen together. A subsequent treatment at the appropriate time would, therefore, be more effective because of the high number of anagen hairs at the time of treatment. This effect may reduce the number of treatments required for adequate results.

A question arises from this discussion as to what is the optimal retreatment time. Most multiple treatment studies have empirically lased every 4 to 6 weeks. Theoretically, this time should be based on the hair cycle of the region being treated. For instance, if it is true that nonlethal affected hair tends to enter telogen and it is best to treat a hair in early anagen, then the length of time in the telogen cycle for a particular body region must be known in order to determine the optimum treatment interval; however, a laser-induced telogen may differ in length from a natural telogen stage. Therefore, data should be collected to determine the length of laser induced telogen for a particular site. Alternatively and more practically, another solution would be to have the patient observe the treated area for hair regrowth. Assuming that early anagen is the best treatment stage, this can be roughly approximated when the first hair shafts begin to break the skin surface. Treatment at this time should catch the highest number of hairs in early anagen and theoretically achieve the best results.

HISTOLOGY

A common question regarding TSALHR is whether or not carbon truly gets into the hair-follicle. Histologic evidence of carbon in a hair follicle after low fluence lasing has been demonstrated. Carbon penetration into the follicle occurs with and without a hair shaft in place (Figs. 19 and 20). Examination of multiple histologic specimens reveals that carbon penetrates superficially in a large number of follicles, but deep penetration occurs in a much lower percentage.

The microscopic appearance of the hair follicle following Nd:YAG laser exposure has been examined in a recent study. Test squares on the trunk and extremities were treated twice at 1-month intervals using different methods including waxing, shaving, wax-carbon-laser, and carbon-laser. Each site was biopsied immediately after the second treatment, formalin fixed, and processed for hematoxylin and eosin (H&E) staining.

Figure 21 shows a control hair bulb that was shaved alone. Several features may be noted for comparison with the lased specimens. The hair papilla is symmetrical, evenly staining, with a normal nuclear and vascular number and appearance. The hair matrix is evenly stained, shows symmetry, and demonstrates no separa-

Figure 19. Carbon can be seen as the black substance in the follicle. Note the presence of a hair shaft (hematoxylin and eosin staining, original magnification x 2.5).
tion between or disruption of the cells. The dermal sheath is contiguous with the hair papilla and is normal in thickness and vascu-

larity.

In contrast, Figure 22 shows a hair bulb immediately after the second wax-carbon-laser treatment. The hair papilla and dermal sheath show enlarged and engorged vessels and the hair matrix is markedly disrupted with separation and disarray of all cells. Figure 23 shows another follicle 1 week after one treatment with the carbon-laser technique. The hair matrix is again totally disrupted with loss of cells during processing. The hair papilla is somewhat asymmetrical with fewer nuclei than normal and incontinence of melanin, possibly left from damaged matrix keratinocytes. Ectatic, engorged vessels can be seen in a clearly thickened dermal sheath.

Figure 24 is electron microscopy of follicular

Figure 20. A and B, Carbon can be seen as the black substance in the follicle (hematoxylin and eosin staining, original magnification x 2.5).

Figure 21. A normal control hair bulb (shaved only) (hematoxylin and eosin staining, original magnification x 10).
keratinocytes after shaving alone and shaving plus lasing with the carbon-laser technique. Clearly evident are an increased number of vacuoles in the lased specimen compared to areas that were only shaved. This is because of target vaporization and subsequent bubble formation.

One of the safest instruments for laser hair removal is the Nd:YAG laser. This is true no matter what the skin type (Fig. 25). Skin types I to VI are shown microscopically immediately after Nd:YAG laser exposure at 1064 nm. Even the darkest skin shows no obvious changes after treatment. This is because of the relatively weak absorption of melanin at this wavelength.

It has been observed that lasing with the Nd:YAG laser frequently induces telogen in sublethally damaged follicles (Fig. 26). This may be because of the photo mechanical dam

Figure 22. A lased hair bulb immediately after the second treatment (wax-carbonlase) (hematoxylin and eosin staining, original magnification x 10).

Figure 23. A lased hair bulb 1 week after a single treatment (carbon-lase) (hematoxylin and eosin staining, original magnification x 10).
age induced by laser pulses. The significance of this finding is discussed in the section on Clinical Studies.

PRACTICAL CONSIDERATIONS

Preoperative Evaluation

One of the most important aspects of preoperative preparation is to counsel patients so that they will have realistic expectations. As with any cosmetic procedure, if the patient has higher expectations than can be met, reasonable results can garner disappointment, agitation, or possibly anger. Therefore it is important that patients understand several things; clearly, no guarantees can be made in any medical procedure. This must be acceptable or the individual should not be treated. Multiple treatments will be required for best results as, apparently, only early anagen hairs respond well. It should be understood that four to six treatments will be done. The best time interval for treatment is probably when hairs first begin to regrow and this occurs
Figure 25. The range of skin types immediately after lasing (carbon-lase) (hematoxylin and eosin staining, original magnification x 5).

Figure 26. Hair bulbs from plucked hairs. A, Hairs plucked 6 days after lasing. Note the tapering of the hair bulb region. B, Control hairs plucked at day 6 (no lasing). These hairs demonstrate a typical anagen hair bulb.
approximately every 4 to 8 weeks. Depending on the individual, the duration of effect may be 3 to 12 months or rarely longer. Patients should know that even though a certain decrease in the number of hairs will occur, total hair loss may not occur. It is likely that some percentage of hairs will persist after treatment. It is apparently possible to achieve permanent hair removal in any given hair with several available laser systems, but this permanence will almost certainly be less than 100%. It is important to clarify the difference between permanent (an individual hair is gone forever) and total or complete (all hairs are gone for a variable time period).

For best results, an underlying cause for excess hair should be addressed before treatment. In many cases, hirsutism and hypertrichosis both can be ameliorated simply by treating their etiology. The reduction in hair density by laser treatment should be improved once the inciting agent is removed.

Each of the available light systems for hair removal is absorbed by melanin. The Nd:YAG laser, though least well absorbed, still can affect cutaneous melanin. Because of this, skin type becomes an issue. It is best to treat a patient when at their lightest, untanned skin color. Treating types I to IV with a low fluence Nd:YAG laser (Thermo Lase, San Diego, CA) presents essentially no problem with dyspigmentation. The only patients who have exhibited any postoperative cutaneous pigment change are those with skin types V and VI. In these individuals, two main responses have been noted. The first and largest group of patients experiences no pigmen
tary change. The second group develops superficial crusts following treatment. The skin may take on a slightly grayish hue or be more erythematous than usual during treatment. Crusts develop in several days and peel off within a week. When the crust desquamates, no pigment is left in the skin, presenting a stark contrast to the normal dark cutaneous pigment. It is important to assure the patient that the pigment will return in these areas within 2 weeks and to suggest a cover-up cosmetic (e.g. Dermablend, Covermark) during the interim. Only one long-term case of dyspigmentation has been noted using low fluence Nd:YAG lasers and no permanent cases have been noted. The number may be increased with higher fluence systems as more energy is deposited and the epidermis is more easily ablated because of photomechanical disruption. It may be that lower fluences (≠2.0 J/cm²) or longer pulse durations, where the epidermis can be effectively cooled, will further decrease the incidence of temporary dyspigmentation in darkly pigmented subjects. Lastly, it should be remembered that melanin absorbs 1064-nm Nd:YAG laser light less than any other hair removal light system. It is, therefore, the best choice for minimizing the risk of possible dyspigmentation in patients with darker skin types.

It is important to take a thorough history before treatment (Display Box 1). Any medications that could possibly induce hypertrichosis should be discontinued. Topical agents that could cause skin sensitivity should be avoided for at least 48 hours prior to treatment. It is advisable to wait perhaps 6 to 12 months following discontinuation of accutane before treatment.

Display Box 1. History

<table>
<thead>
<tr>
<th>Medications</th>
<th>Hypertrichosis-inducing (cyclopentolate, minoxidil, steroids)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accutane</td>
<td>Topical retinoids, glycolic acid</td>
</tr>
<tr>
<td>Illnesses</td>
<td>Infections-hepatitis, herpes, HIV</td>
</tr>
<tr>
<td></td>
<td>Neoplasm-androgen producing</td>
</tr>
<tr>
<td></td>
<td>Endocrine-polyycystic ovary disease, Cushings</td>
</tr>
<tr>
<td></td>
<td>Cutaneous-koebnerizing, e.g., psoriasis, vitiligo keloid, hypertrophic scar dyspigmentation after injury skin type</td>
</tr>
<tr>
<td></td>
<td>Prior Procedure/Surgery</td>
</tr>
<tr>
<td></td>
<td>Chemical peels, other laser, surgery, burns</td>
</tr>
<tr>
<td></td>
<td>Previous Treatment</td>
</tr>
<tr>
<td></td>
<td>Waxing</td>
</tr>
<tr>
<td></td>
<td>Tweezing</td>
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<tr>
<td></td>
<td>Depilatory</td>
</tr>
<tr>
<td></td>
<td>Shaving</td>
</tr>
<tr>
<td></td>
<td>Electrolysis</td>
</tr>
<tr>
<td></td>
<td>Laser/light source</td>
</tr>
<tr>
<td></td>
<td>Other hair removal</td>
</tr>
<tr>
<td></td>
<td>Last hair removal date</td>
</tr>
<tr>
<td></td>
<td>Last Menstrual Period</td>
</tr>
<tr>
<td></td>
<td>Currently Pregnant?</td>
</tr>
<tr>
<td></td>
<td>Tattoos or Permanent Cosmetics</td>
</tr>
</tbody>
</table>
Treating an underlying cause of excess hair such as an endocrine or neoplastic condition is essential and should improve results. Awareness of an infectious disorder is crucial to protect the health of the operator. Q-switched lasers, in particular, can vaporize tissue, sending infectious particles airborne. It is recommended to premedicate those patients with a history of herpes simplex virus in the treatment site with an antiviral drug. Possible regimens would include acyclovir 400 mg by mouth 3 times a day or famciclovir 125 mg by mouth twice a day for 5 days beginning 24 hours prior to the procedure. Small tests in the area proposed to be treated should be done in patients with koebnerizing conditions, keloids, and skin types V and VI or a history of long-term dyspigmentation after cutaneous injury. Recommended waiting periods after testing are 2 weeks, 4 weeks, and 1 week respectively.

Other significant history includes the last hair removal technique and date. It is preferable to have an accurate idea of the severity of the problem with good baseline photographs. A realistic baseline is obtained only after all previously treated hair is allowed to regrow. Postoperative assessment should be compared to full hair growth at the baseline. In addition, treating follicles without hair removes the chromophore melanin found in the hair shaft. Without the chromophore, poorer results would be expected unless a topical chromophore is well distributed in the follicle. No hair removal method except trimming or shaving should be used 4 to 6 weeks before laser treatment.

During menstruation, the skin is more sensitive to pain. Though treatment with the Q-switched Nd:YAG laser is not very painful, it may be better tolerated if done off the menstrual period. Pregnant females are normally not treated, because if a fetal problem should develop postoperatively, the role of the procedure will be called into question. It is essential to know the site of all tattoos as the color and intensity will likely be changed if lased.

The physician should be aware of any injury or procedure to the skin in the area of treatment. Chemical peels, other laser treatments, surgery, or severe burns may alter the homeostasis of the skin for months. The skin should appear normal in color, integrity, and texture before laser treatment is undertaken. Abnormalities may inhibit laser light penetration and possibly increase side effects. Finally, the cost of the procedure should be discussed with the patient and recorded on a document to be signed by the physician and patient.

**Skin Preparation and Treatment**

Minimal skin preparation is required prior to Nd:YAG laser hair removal; however, a few points should be noted. It is preferable to pretreat skin types V and VI with a bleaching cream 4 to 6 weeks prior to treatment. To enhance the bleaching effect, a topical retinoid is often used concomitantly. Clearly, most pigment will remain even after 6 weeks of this regimen. The idea is to treat the skin when it is at the lightest color possible to minimize the chances for side effects (especially dyspigmentation) and facilitate the passage of light to the hair bulb. Protection from sun exposure and daily sunscreen (≥ SPF-15) are used in concert with the pigment bleaching. Hair should be shaved the day prior to treatment. In this manner, the chromophore in the hair shaft is maintained, but the necessity of light penetration through long hair is avoided.

No lotions, creams, or make-up should be worn the day of treatment. Rarely, a topical anesthetic may be requested in sensitive areas such as perioral. If used, it should be applied generously under occlusion 1.5 to 2 hours before the scheduled appointment. Remove the anesthetic just prior to lasing as the anesthetic effect abates rapidly. If a topical suspension is used, it should be massaged into the skin and the excess removed. Lasing is then undertaken. The ThermoLase system uses a fluence of 2.5 to 3.0 J/cm², a spot size of 7 mm, and a repetition rate of 10 Hz. Four passes are normally made over one area before progressing to the next. The end point is vaporization of all carbon in the site of treatment. Vaporization can be seen as a white flashing. This is replaced by a green cutaneous fluorescence once the carbon is gone. Higher fluence Q-switched Nd:YAG lasers require only one to two passes as epidermal disruption occurs early, decreasing transmittance of subsequent lasing.


**Postoperative Care**

Low fluence Q-switched Nd:YAG lasers produce mild erythema and edema, which subside in less than 24 hours and usually within an hour following treatment (Display Box 2). Cool compresses will hasten resolution. A physical urticaria, possibly from heat, has been seen in some individuals with skin types V and VI. If this is a significant problem, it is possible that a preoperative antihistamine be administered 30 minutes before treatment to decrease or eliminate this reaction. Cool compresses applied postoperatively will also help to clear these symptoms. Several laser hair removal systems employ cooling during treatment to decrease side effects. If the epidermis is cooled just prior to and during treatment, it can withstand more heat before problems occur. This decreases the chances of adverse events such as vesiculation, crusting, burning and resulting dyspigmentation. Because Q-switched laser complications tend to be owing to a photomechanical effect more than to a photothermal effect, such cooling is not essential or effective. Fortunately, low fluence Q-switched Nd:YAG lasers do not produce these problems. High fluence instruments disrupt the epidermis with or without cooling. Following lasing, the skin is cleaned with a mild cleanser as needed. Sunscreen should continue to be used on a daily basis. Follow-up should occur in 4 to 6 weeks.

**Display Box 2. Potential Side Effects of Nd:YAG Laser Hair Removal**

<table>
<thead>
<tr>
<th>Common</th>
<th>Rare</th>
</tr>
</thead>
<tbody>
<tr>
<td>Erythema</td>
<td>Urticaria</td>
</tr>
<tr>
<td>Edema</td>
<td>Pain</td>
</tr>
<tr>
<td></td>
<td>Dyspigmentation</td>
</tr>
<tr>
<td>Very rare</td>
<td>Vesiculation</td>
</tr>
<tr>
<td></td>
<td>Crusting</td>
</tr>
<tr>
<td></td>
<td>Burn</td>
</tr>
<tr>
<td>Epidermal disruption (common with high fluence lasers)</td>
<td>Infection</td>
</tr>
</tbody>
</table>

**Other Issues**

As with any medical procedure, different body sites have varying responses to treatment. In general, the body sites that appear to have best results are the legs and bikini area. Intermediate responses can be expected from the trunk, axillae, cheeks, and upper lip. The most resistant area tends to be the chin.

The goal of treatment is ultimately to improve the appearance of the patient by decreasing hair number or rendering hair less apparent. Making hair imperceptible may be achieved in a number of ways. Changing hair color from dark to light will make it harder for an observer to notice. The Q-switched Nd:YAG laser has been shown to cause leukotrichia in lab animals4 and also does so in clinical practice; however, this effect usually lasts less than 1 month. Another way to make hair undetectable is to decrease its size and length. A male with Hamilton type VIII androgenic alopecia has many short, fine hairs in the affected area on close observation; however, he still appears to have no hair. The Nd:YAG laser and other lasers have been noted to decrease hair size and length, making it less apparent. In addition, a decrease in hair number by hair count may simply represent a decrease in the perceptible hairs. Fine, vellus hairs are difficult to see on photographic hair counts and many are still present on scrutinization of the treated area. The clinical result may still be perceived to be very good because of the replacement of large, terminal hairs with invisible, vellus hairs.

**FUTURE DIRECTION**

One-micron laser light is a good wavelength for hair removal in that it penetrates well and has relatively little absorption by surrounding skin structures. Longer wavelengths are absorbed more by water and shorter wavelengths by melanin and hemoglobin. More cutaneous absorption results in a greater likelihood of side effects as well as decreased transmission. One micron is, therefore, both safe and penetrating. The most challenging aspect of effectively using this wavelength is saturating the follicle with a
strong chromophore. Because it is not as well absorbed by melanin as are shorter wavelengths, the Nd:YAG laser alone would be expected to be less effective for epilation than wavelengths that are more strongly absorbed by melanin. A potent, well-placed exogenous target would help to attract this light. Therefore, this points the direction for future study: the development of methods that would consistently distribute a strongly absorbing chromophore (at 1064 nm) throughout the follicle.

At this time a suspension is used with the ThermoLase technique. The particulate nature of a suspension makes penetration into a hair follicle more difficult. Diffusion down a hair follicle would most likely be easier and improved using a solution. A molecular chromophore dissolved in water or other penetrating vehicle might be a good choice. If the solution is applied topically and either diffuses down the hair follicle or is taken up by follicular keratinocytes, good distribution may be possible. There is some indication that this can be done with liposomes.43 In a recent study, melanin was incorporated into liposomes and applied topically to histocultured skin of amelanotic mice. It was shown that melanin was actually taken up by follicular keratinocytes and subsequently incorporated into the hair shaft. A control site, in which melanin without liposomes was applied, showed no follicular pigment. This was demonstrated by H & E staining and fluorescein-labeled melanin. This is an area of ongoing research.

Diffusion of a topically applied compound has also been shown to occur with photodynamic therapy. A topical solution containing aminolevulinic acid (ALA) is applied and taken up by cutaneous structures. After a period of washout, tumors (e.g., basal cell carcinoma) retain ALA relative to surrounding skin. Subsequent treatment with an appropriate intense light source, usually at 630 nm, causes a photochemical reaction leading to reactive oxygen intermediates that damage tumors. The same approach is being used for a variety of other cutaneous targets including the hair follicle. 22 ALA-containing liposomes have proven to be a more effective follicular delivery system when used with this substance.

At this time, only nanosecond pulsed Nd:YAG lasers are available for hair removal. As previously stated in the section on Pulse Duration, a longer millisecond pulse duration should be effective, assuming the presence of a strong chromophore or high fluence. A Nd:YAG laser with a pulsewidth between 10 and 60 msec, a beam size of 10 mm, and a repetition rate of 5 Hz (or a scanning device) would perhaps be a good choice. This should be studied further.

CONCLUSION

As indicated, l-micron laser light has many advantages. The nanosecond Nd:YAG laser has proven exceptionally safe. Side effects are fewer and of shorter duration than with any other light-based hair removal system. It is a practical instrument for treating large areas such as the back or legs. A large beam diameter and a quick repetition rate make this possible. Finally, it has been shown to be effective for short-term hair reduction. Some study subjects have demonstrated hair loss for up to 1 year. Longer-lasting hair reduction may be achieved with modifications such as improved chromophore distribution and millisecond domain pulses. Therefore, if a strongly absorbing topical chromophore can be well distributed in the hair follicle, a system as described above may be able to permanently and consistently eradicate hair. Studies to determine the feasibility and effectiveness of such a technique are ongoing.

ACKNOWLEDGMENT

The author wishes to gratefully acknowledge information supplied by the ThermoLase Corporation (San Diego, CA).

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HAIR REMOVAL USING AN Nd:YAG LASER SYSTEM


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