Permanent Hair Removal by Normal-Mode Ruby Laser

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Objective: To assess the permanence of hair removal by normal-mode ruby laser treatment.

Methods: Hair removal was measured for 2 years after a single treatment with normal-mode ruby laser pulses (694 nm, 270 microseconds, 6-mm beam diameter).

Observations: Six test areas on the thighs or backs of 13 volunteers were exposed to normal-mode ruby laser pulses at fluences of 30 to 60 J/cm² delivered to both shaved and wax-epilated skin. In addition, there was a shaved and wax-epilated control site. Terminal hairs were manually counted before and after laser exposure. Transient alopecia occurred in all 13 participants after laser exposure, consistent with induction of telogen. Two years after laser exposure, 4 participants still had obvious, significant hair loss at all laser-treated sites compared with the unexposed shaved and wax-epilated control sites. In all 4 participants, there was no significant change in hair counts 6 months, 1 year, and 2 years after laser exposure. Laser-induced alopecia correlated histologically with miniaturized, velluslike hair follicles. No scarring and no permanent pigmentary changes were observed.

Conclusions: Permanent, nonscarring alopecia can be induced by a single treatment with high-fluence ruby laser pulses. Miniaturization of the terminal hair follicles seems to account for this response.

Arch Dermatol. 1998;134:837-842

Unwanted hair is a major cosmetic and surgical problem. Many temporary hair removal methods exist, including shaving, wax epilation, and use of chemical depilatories. Electrolysis is a well-established method for permanent destruction of terminal hair follicles. However, the method is tedious, and efficacy has been reported to range from 15% to 50% permanent hair loss. Scarring can occur after electrolysis, especially if inexpertly performed.

Damage to hair follicles based on the theory of selective photothermolysis has been reported recently. Thirteen volunteers with brown or black hair were exposed to normal-mode ruby laser pulses (694 nm, 270 microseconds, 6-mm beam diameter) at fluences of 30 to 60 J/cm² delivered to both shaved and wax-epilated skin sites on the thighs or back. In all 13 participants, laser exposures produced a hair growth delay consistent with induction of telogen. Ruby lasers have been commercialized for hair removal, but the question remains whether permanent hair loss can be induced by selective photothermolysis. Four study participants had clinically obvious hair loss at the final follow-up visit 6 months after exposure, each of these with less than 50% regrowth of terminal hairs. We decided to follow up the participants of this first study at 1 and 2 years after laser exposure to evaluate the permanence of hair removal.

Results at 6 months' follow-up have been published previously but did not address the question of permanent hair loss. Of the 13 participants, 7 were followed up for 2 years after laser exposure.
PARTICIPANTS AND METHODS

Thirteen adult volunteers (12 men and 1 woman) consented to participate, as previously described. All had fair skin (Fitzpatrick type I, II, or III) and brown or black hair. Test sites were chosen on the back or posterior aspect of the thighs based on uniformity and density of terminal hairs. Eight 3 × 2-cm areas were mapped and photographed. Baseline hair counts were obtained from each site by manually counting and marking terminal hairs. Before laser exposure, half of the test sites were shaved and half were epilated with cold wax (My-Epil, Laboratoire Suzy, Montreuil, France). Sites were irradiated with a normal-mode ruby laser, described below, at fluences of 0 (unexposed control), 30, 40, and 60 J/cm². Laser pulses were given in a contiguous, nominally nonoverlapping pattern that covered the entire test site.

Clinical evaluation, terminal hair counts, and photographs were obtained 1, 3, 6, 12, and 24 months after laser exposure. One participant who had obvious alopecia in all laser exposure sites at all of these follow-up visits consented to biopsy examination. Three-millimeter punch biopsy samples were obtained before treatment and at 1 year after laser exposure from a site with alopecia treated at 60 J/cm² after shaving. Tissue specimens were processed for light microscopy of horizontal sections with a technique using trisection or quadrisection that maintains all sections in the same anatomic orientation (deep to superficial) on the microscope slides. All specimens were stained with hematoxylin-eosin for light microscopy.

At 1 year and 2 years after laser treatment, 4 of these 7 participants still had obvious hair loss confined to laser-treated sites and 3 had complete or nearly complete hair regrowth. In all 7 participants, there was no significant change in terminal hair counts 6 months, 1 year, and 2 years after laser exposure.

Figure 1, left, illustrates hair loss on a participant’s back 1 year after laser exposure. The hair loss is fluence dependent, with the greatest loss at the highest fluence (60 J/cm²). Figure 1, right, illustrates the same sites 2 years after treatment. The same amount of hair loss is still present. Figure 2, top and bottom, show the same site on an upper thigh treated with 60 J/cm² at 3 months and 2 years, respectively. No substantial change in the clinical appearance of the alopecia is seen. Neither pigment changes nor scarring was seen in any participant at the 12- and 24-month follow-up visits.

Hair loss at 6, 12, and 24 months after a single laser exposure in the 4 participants showing permanent hair loss are plotted vs fluence in Figure 3. Sites treated with 60 J/cm² (highest fluence) after shaving had the greatest hair loss, 64.3% ± 1.1%. Statistically significant hair loss was seen at 6 months for all fluences at both shaved and epilated sites compared with the unexposed shaved and epilated control sites. At 1 year and 2 years, there was significantly less hair only in the shaved sites for all fluences compared with the untreated control site.

DATA ANALYSIS

Hair loss was defined as the percentage of terminal hairs absent after treatment compared with the number before treatment. For each site, at each follow-up visit, hair loss was calculated. Results for each experimental condition were pooled for all participants. The mean ± SD for each condition was calculated. A paired t test was used to determine significant differences (P < .05) between post-treatment and pretreatment hair counts for each experimental condition at the 6-, 12-, and 24-month observation times.

LASER AND DELIVERY APPARATUS

A normal-mode, flashlamp-pumped, 694-nm ruby laser with a 270-microsecond pulse duration and a 6-mm spot size was used (model 936R4H-2, Lasermetrics, Winter Park, Fla). The beam was steered via an articulated arm into an actively cooled “hand piece” designed to maximize delivery of light into the reticular dermis while minimizing epidermal injury. A planoconvex sapphire lens (approximately 20-mm focal length) was used to provide a convergent beam at the skin surface and to increase beam coupling into the skin compared with air as an external medium. The sapphire lens was cooled to 4°C to provide heat conduction from the epidermis before, during, and after each laser pulse. The convex surface of the cold sapphire lens was pressed firmly against the skin before delivery of each laser pulse. Delivered pulse energy into air was measured with a laser energy meter (model 351, Scientech, Boulder, Colo).

HISTOLOGICAL FINDINGS

Terminal and velluslike (miniaturized) hairs were identified on the transverse sections and counted by established criteria. Terminal-velluslike hair ratios were calculated from the follicular counts; and fibrous tracts were recorded as absent or present. Results are shown in the Table. The total number of hairs was identical in the control and laser-treated sites. However, in the laser-treated sites, there was a reduction in large terminal hairs with a reciprocal increase in small velluslike hairs. The average hair shaft diameter measured from the histological sections also decreased after laser treatment (Figure 4). There were no signs of fibrous tracts, and normal-appearing sebaceous glands were still present around the miniaturized hair follicles.

COMMENT

The results of this study show that permanent loss of terminal (coarse) hair can result from a single treatment with high-fluence, normal-mode ruby laser pulses. The lack of change in any participant’s terminal hair counts beyond 6 months after laser exposure...
suggests that 6 months' follow-up may be sufficient to assess final outcome after treatment for hair removal.

The mechanisms by which high-fluence, normal-mode ruby laser pulses induce selective damage to hair follicles are based on the principles of selective photothermolysis. At 694 nm, light penetrates well into and through the dermis, and follicular melanin is by far the dominant chromophore in the dermis. Laser pulse width also seems to play an important role, as suggested by the thermal transfer theory. Thermal conduction during the laser pulse heats a region around each microscopic site of optical energy absorption. The spatial scale of thermal confinement and resulting thermal or thermomechanical damage is therefore strongly related to laser pulse width. Q-switched (nanosecond domain) laser pulses effectively damage individual pigmented cells within hair follicles by confinement of heat at the spatial level of melanosomes, leading in animals to leukotrichia but not to hair loss after Q-switched ruby laser pulses. Consistent with this behavior, permanent hair loss has not been reported in humans after Q-switched laser treatment despite a decade of widely using Q-switched ruby and Nd:YAG lasers for tattoo removal. The thermal relaxation time of whole hair follicles is between 1 and 100 milliseconds, depending on size. Thermal relaxation of human terminal hair follicles has never been measured but is estimated to be about 10 to 50 milliseconds.

The 0.27-millisecond ruby laser pulses used in this study were clearly long enough to cause thermal coagulation and vaporization injury of hair follicles, leading to a growth delay in all participants and permanent hair loss in some. However, in theory, the longer-pulse (3-millisecond) ruby laser now commercially available for hair removal may be more ideal for several reasons. First, it is still unknown which "targets" in hair follicles are responsible for permanent hair loss. A somewhat...
longer pulse width should allow more thermal conduction and damage to nonpigmented regions of the hair follicle but retain confinement on the spatial scale of the follicle itself. Second, the efficiency of extracting heat from the epidermis during each laser pulse into cold sapphire in contact with the skin surface should be improved with the longer laser pulse.

The biologic mechanisms by which ruby laser pulses cause permanent loss of terminal hair remain unknown. However, this study strongly suggests that miniaturization of coarse terminal hair follicles to velluslike hair follicles is involved, producing nonscarring alopecia. Only 1 participant with laser-induced alopecia was examined histologically 1 year after laser exposure, and more should be studied as the number of people with laser-induced alopecia grows. In this participant, however, there was an absence of fibrosis or any remnant of laser-damaged hair follicles, a decrease in terminal hair follicles, and a reciprocal increase in miniature hair follicles. These histological findings are also consistent with clinical observations. A miniaturized terminal hair or secondary vellus hair is arbitrarily defined as having a cross-sectional hair shaft diameter of less than 30 mm. Because the size of a hair depends on the size of the papilla and the hair bulb, ruby laser pulses seem to miniaturize the papilla and the bulb either by direct photothermal injury or by injury to other structures of the follicle that control formation of the bulb with each anagen cycle.

The histological picture of miniaturized follicles after ruby laser pulses corresponds with the histological picture of androgenetic alopecia. Male baldness is characterized by a proportional reduction in size of the papilla and the matrix. Therefore, the terminal follicles are gradually transformed to velluslike follicles. “Loss” of hair in androgenetic alopecia only relates to the loss of terminal hairs and is similar to “loss” of hair after ruby laser treatment. The follicles are not actually lost but produce hairs that are shorter, finer, and less pigmented. These miniaturized follicles still have arrector pili muscles. Pluripotent stem cells of the bulge—a region of follicular epithelium near the insertion of the arrector pili muscles—regenerate epidermis during wound healing. To the extent that ruby laser-induced alopecia is like male pattern alopecia, wound healing should not be largely affected after laser hair removal.

We hypothesize and suggest that the 2 distinct responses—growth delay and permanent hair loss—are caused by induction of telogen and miniaturization of terminal hair follicles, respectively. Numerous observations are explained by this hypothesis. In all 13 participants, whether they had measurable permanent

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**Table:**

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<thead>
<tr>
<th></th>
<th>Before Laser Treatment</th>
<th>1 y After Laser Exposure</th>
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<tbody>
<tr>
<td>Terminal hairs, No.</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Velluslike hairs, No.</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Total hairs, No.</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Terminal-velluslike ratio</td>
<td>3.1</td>
<td>1.3</td>
</tr>
<tr>
<td>Average (mean±SD) hair shaft diameter, µm</td>
<td>68.7 ± 44.2</td>
<td>22.5 ± 12.2</td>
</tr>
<tr>
<td>Fibrous tracts</td>
<td>Absent</td>
<td>Absent</td>
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*Hair counts were done on transverse sections at ×4 magnification.*
hair loss or not, there was a growth delay consistent in length with telogen. Presence of the hair shaft during laser exposure was not essential to induce growth delay, which occurred at all fluences in both shaved and epilated sites in all participants. Presumably, there is enough melanin present because epilation typically breaks the hair shaft above, in the upper third of, or at the midlevel of the bulb. In contrast, permanent hair loss after a single laser exposure was significant only in sites that were shaved (hair shaft present) rather than wax epilated and was fluence dependent. Both responses are clinically significant and may be separately desirable to different patients. Growth delay that provides a few months of hairless skin is far more reliable and requires lower fluences than permanent hair loss. Permanent hair loss occurred in this study in only 4 of the 13 participants after a single treatment.

Knowledge of the hair cycle and particularly of the length of telogen is essential for interpretation of the results of this study. At present, no consensus exists on a definition for treatment-induced “permanent” hair loss despite frequent use of the term to describe the effects of electrolysis. We suggest, and hereby use, the following specific definition: “permanent” hair loss is a significant reduction in the number of terminal hairs after a given treatment that is stable for a period longer than the complete growth cycle of hair follicles at the given body site. Telogen may last for 3 to 7 months on the thighs and chest, after which the follicle will recycle into anagen, which also lasts 3 to 7 months on the body. Our observation period of 24 months after a single laser treatment therefore spans 2 to 4 complete growth cycles, depending on the length of the telogen phase. The data show gradual reappearance of terminal hair up to 6 months after laser exposure, which is consistent with recovery of terminal hair follicles within 1 growth cycle. Thereafter, the data show no significant difference in hair counts 6 months, 1 year, and 2 years later, which is consistent with no further recovery of terminal hair follicles. This strongly suggests that whatever terminal hair follicles were inactivated at 6 months were also missing for at least 2 years, although we did not map and track individual hair follicles in this study. For studies of laser or other treatments intended to induce hair loss, we suggest that measurements be carried out until a steady state is achieved, which in this study seems to be between 6 months and 1 year. A distinction also needs to be made between permanent and complete hair loss. Complete hair loss refers to a lack of regrowing hairs (ie, a significant reduction in the number of regrowing hairs to zero). Complete hair loss may be either temporary or permanent. Ruby laser treatment usually produces complete hair loss for 1 to 3 months, followed by partial permanent hair loss.

Finally, it is likely, but as yet unproven, that the sensitivity of human hair follicles to laser pulses varies with the hair growth cycle. In this study of responses after a single treatment, the hairs “resistant” to permanent inactivation by laser treatment may have been mainly in the telogen stage at the time of exposure. On the thighs, up to 72% of the hairs are in telogen. Selective photothermolysis requires absorption of light, and the bulb of a telogen hair is unpigmented because of cessation of melanogenesis during catagen. On the other hand, as anagen progresses, the bulb and papillae descend deeply into the dermis and beyond such that late anagen hairs may also be relatively resistant to laser pulse injury. By this reasoning, follicles should be most easily inactivated by laser pulses during early anagen. If so, the reliable induction of telogen with a single laser treatment, as we suggest, has profound clinical implications. As the “surviving” terminal follicles transition into anagen, after growth delay, a second treatment may be more effective than the first. On the contrary, a second treatment given too early or too late may have little effect. We are presently investigating these interesting questions.
REFERENCES