The Effect of Different Spot Sizes on the Efficacy of Hair Removal Using a Long-Pulsed Diode Laser

WOLFGANG BÄUMLER, PHD, KATHRIN SCHERER, MD, CHRISTOPH ABELS, MD, SABINE NEFF, MD, MICHAEL LANDTHALER, MD, AND ROLF-MARKUS SZEIMIES, MD

Department of Dermatology, University of Regensburg, Regensburg, Germany

BACKGROUND. **In the last years several lasers have proven their efficacy for hair removal. However, little is known about the efficacy of varying the spot size with those lasers.**

OBJECTIVE. **To evaluate the long-term efficacy of hair removal using a diode laser with different spot sizes.**

METHODS. **A long-pulsed diode laser (2 × 60 msec) was used. The spot size was 8 mm, 12 mm, or 14 mm. Twenty consenting volunteers were treated three times at regular intervals of 3 weeks. The ratio of the number of hairs in the treated area to an adjacent area left untreated (control) was referred to as regrowth.**

RESULTS. **One month after laser treatment, regrowth was 23% (8 mm), 12% (12 mm), and 13% (14 mm). After 3 months regrowth was 67% (8 mm), 54% (12 mm), and 55% (14 mm). Fifteen months after treatment 4 of 16 volunteers had a regrowth rate of less than 25%.**

CONCLUSION. **The results provide evidence for an effective and long-lasting growth delay of hairs using the long-pulsed diode laser. The use of large spot sizes improved the growth delay of hairs measured 1 month after treatment.**

MANY PATIENTS complain of excessive hair growth, as seen in hirsutism and hypertrichosis. Various conventional methods for hair removal such as shaving, wax epilation, plucking, chemical depilatories, and electrolysis are very time-consuming and often are accompanied by side effects such as folliculitis and scar formation. In the last few years the technology of laser-assisted hair removal has advanced rapidly. Effective results have been achieved with ruby laser,[1] alexandrite laser,[2] diode laser,[3] Nd:YAG laser,[4] and flashlamp systems.[5]

Laser irradiation parameters such as wavelength, fluence, and pulse duration have been shown to clearly influence the damage of any target inside the skin. The careful choice of these parameters can result in confining laser injury to specific targets in tissue.[6] Regarding hair removal the bulge and the dermal papilla appear to be important targets for laser treatment,[7] whereas melanin is the natural chromophore within the hair follicle. The thermal relaxation time of the entire follicle is estimated to be 40–100 msec. There are several studies that examine the clinical efficacy and the side effects of lasers using pulse durations up to 50 msec and fluences up to 100 J/cm^2.[8,9]

The spot size, a parameter not frequently investigated, has been shown to be relevant.[10] The spot sizes applied for hair removal are different for the various laser systems used,[8] ranging from 5 to 15 mm and up to 450 mm^2 in the case of rectangular spots. Recently Littler[11] showed that the optical transmittance of tissue is nearly doubled when increasing the spot size from 5 to 12 mm. Since the depth of follicles is up to 4 mm, a large spot size might improve the therapeutic outcome of the laser-assisted hair removal. Therefore the present study was designed to determine the effect of different spot sizes on the efficacy and the side effects of laser-assisted hair removal using a long-pulsed diode laser.

Materials and Methods

Twenty consenting volunteers (15 women, 5 men) ranging in age from 20 to 42 years, with Fitzpatrick skin types I–III were treated after approval of the protocol by the local institution review board (IRB). Volunteers with photosensitivity, recent sun exposure, pregnancy, or immunosuppression were excluded.

A high-power semiconductor laser was used at 810 nm. The fluence was 44 J/cm^2 when using a spot size of 8 mm, 40 J/cm^2 with a spot size of 12 mm, and 33 J/cm^2 with a spot size of 14 mm. The laser pulse consisted of two pulses with a delay of 40 msec and a duration of 60 msec each. The beam was delivered through an optical fiber and a quartz rod at the distal end of the fiber showing a diameter of 8,

W. Bäumler, PhD, K. Scherer, MD, C. Abels, MD, S. Neff, MD, M. Landthaler, MD, and R.-M. Szeimies, MD have indicated no significant interest with commercial supporters.

Address correspondence and reprint requests to: Wolfgang Bäumler, PhD, Department of Dermatology, University of Regensburg, 93042 Regensburg, Germany, or
e-mail: baeumler.wolfgang@klinik.uni-regensburg.de.

ISSN: 1076-0512/02/$15.00/0 • Dermatol Surg 2002;28:118–121

12, or 14 mm. The quartz rod was contacted to the skin surface by means of a transparent ultrasound gel. Prior to each laser impulse the skin surface was actively cooled using a metal rod, which exhibited a temperature of 0°C using the peltier technology (Figure 1). The volunteers were treated three times on the lower or upper legs at regular time intervals of 3 weeks using an 8, 12, or 14 mm spot size (Figure 2). Three areas (3 cm × 9 cm) were treated using the respective fluence, a fourth area served as control. The laser impulses on the skin were slightly overlapped. No anesthetics were necessary.

The number of regrowing hairs were counted 1 and 3 months after the last laser treatment. The ratio of hairs in the treated area to the untreated area nearby, which served as the control, was referred to as regrowth. The thickness (diameter) of the hairs was measured before and after the last laser treatment using a calibrated conventional microscope. The clinical outcome of the laser therapy was correlated to the color of the hair (black, brown, fair). From each volunteer a punch biopsy specimen was taken 24 hours after the first laser treatment and the specimens were stained with hematoxylin and eosin.

Fifteen months after the last laser treatment the regrowth was evaluated by two independent, blinded observers for the 12 mm spot size (16 of 20 volunteers). For this, a score was used ranging from sparse (<25% hair regrowth), to moderate (25–75% hair regrowth), to full (>75% hair regrowth) according to Campos et al.[3]

Side effects such as erythema, hyperpigmentation, hypopigmentation, and scarring were documented by the investigators. The pain during treatment was assessed on a visual analog scale (0–10). All data are presented as means and standard deviations of the mean. The two-sided *t*-test was used.

Results

One month after laser treatment the regrowth was 23 ± 20% (8 mm), 12 ± 9% (12 mm), and 13 ± 9% (14 mm).

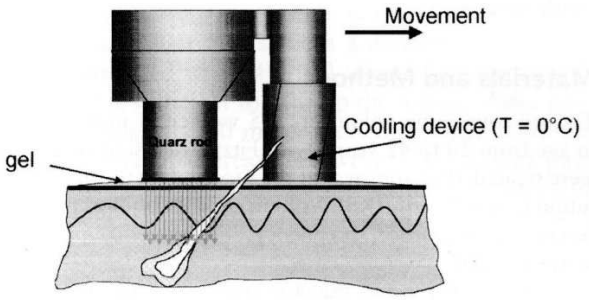

Figure 1. The beam was delivered through an optical fiber and a quartz rod at the distal end of the fiber. The quartz rod was 30 mm long and had a diameter of 8, 12, or 14 mm. The quartz rod was contacted to the skin surface using a gel. Prior to each laser impulse the skin surface was actively cooled using a metal rod (0°C). The movement of the applicator as indicated provides cooling of the skin surface prior to irradiation.

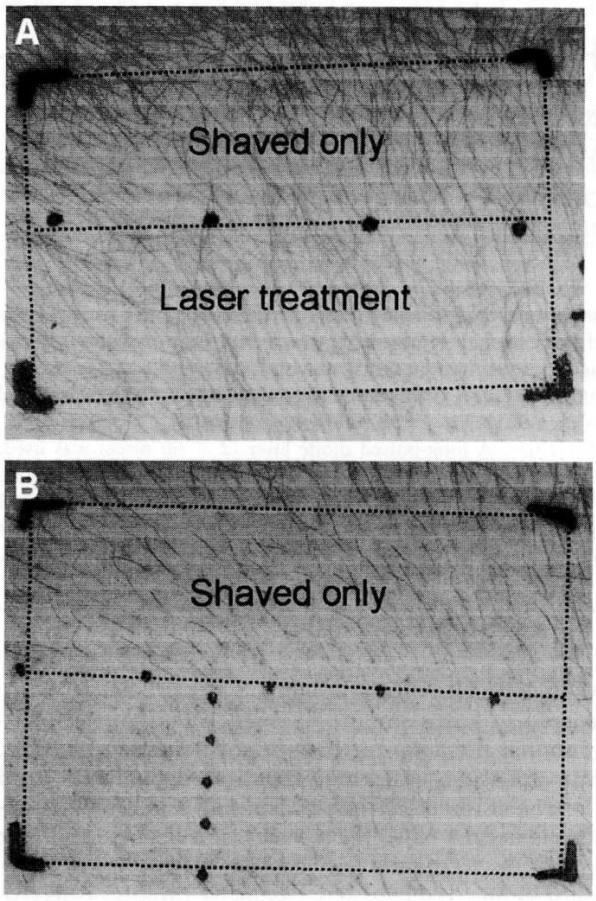

Figure 2. For the different spot sizes, an area of 6 cm × 9 cm was marked on the skin using a permanent marker. The volunteers were instructed to keep the marks on the skin during the term of the study. A) Before treatment the whole area was shaved. B) One-half of the area (3 cm × 9 cm) was treated, the other half served as control during follow-up.

After 3 months regrowth was 67 ± 33% (8 mm), 54 ± 23% (12 mm), and 55 ± 19% (14 mm) (Figure 3). After 15 months the regrowth (12 mm spot size) was sparse in four volunteers, moderate in five volunteers, and full in seven volunteers when evaluating 16 of 20 volunteers.

Histology 24 hours after laser treatment showed fragmentation of the hair shaft, whereas the epidermis remained unaltered. The follicular epithelium was ruptured. The surrounding area exhibited a dense inflammatory infiltrate consisting mainly of neutrophils (Figure 4).

When using the spot size of 12 mm the thickness of the regrowing hairs in the treated area was reduced to 85 ± 15% as compared to the untreated hairs. However, the clinical outcome was correlated to the color of the hair. For example, regrowth was 11 ± 9% for

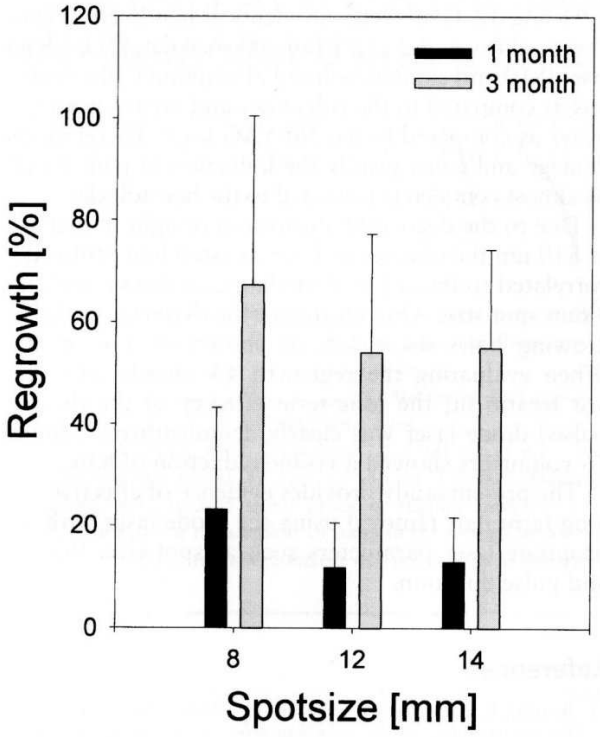

Figure 3. The regrowth of hairs 1 month (black bars) and 3 months after treatment (gray bars). The values are the mean ± standard deviation of the mean regarding the regrowth of the 20 volunteers. One month after the laser treatment the growth delay was significantly different when using a spot size of 8 mm or 12 mm ($P < .01$).

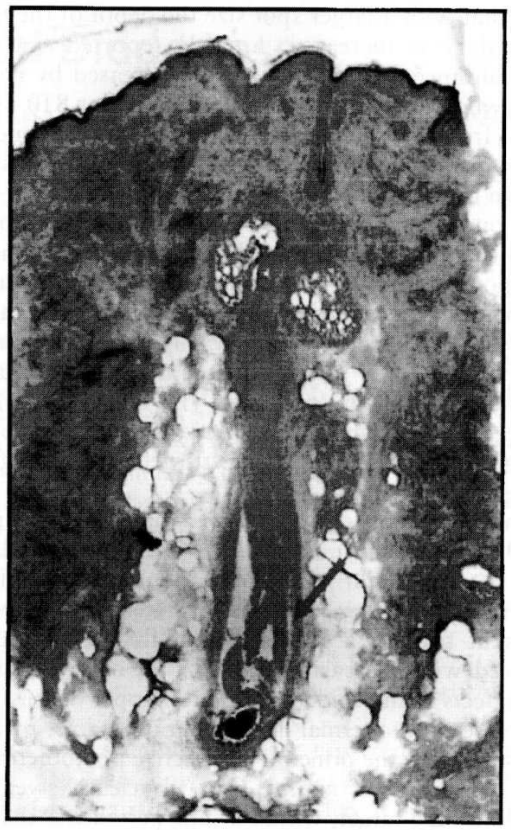

Figure 4. Histology 24 hours after laser treatment showed fragmentation of the hair shaft, whereas the epidermis remained unaltered. The follicular epithelium was ruptured (arrow). The surrounding area exhibited a dense inflammatory infiltrate consisting mainly of neutrophils.

black hair, 26 ± 22% for brown hair, and 31 ± 28% for fair hair (1-month follow-up, spot size 8 mm).

Sixteen volunteers had erythema and perifollicular edema. Transient hypopigmentation was seen in six volunteers. No permanent pigmentary changes, textural changes, or scarring occurred in any volunteer. The different spot sizes did not affect the frequency of side effects, the reduction of hair thickness, or the correlation regarding the color of the hairs and the clinical outcome. The pain during laser treatment was 0.8 ± 0.7 on the analog scale ranging from 0 to 10.

Discussion

The laser-assisted treatment of unwanted hair growth is based on the photothermally induced damage of the hair follicle. In order to prevent hair from regrowing, the anatomic regions of the hair follicle that are responsible for the development of a new hair must be damaged. The stem cells are known to be located in the bulge; during the early anagen phase of the growth cycle stem cells migrate to the dermal papilla where the new hair is being synthesized. Consequently, during the growth phase of the hair the bulge and the dermal papilla should be the main target. Melanin functions as a natural chromophore that sufficiently absorbs light at 810 nm, whereas the hair shaft in the follicle acts as the primary absorber of the applied laser light.[12] In addition, wavelengths at 800 nm are poorly absorbed by competing chromophores such as hemoglobin or water.

The dermal papilla and the hair shaft of anagen hairs are located deep in the skin depending on the anatomic site, ranging from 1 to 4.7 mm.[13] On the upper and lower legs, the depth is 2.5–4 mm.[13] The penetration depth of light into skin significantly depends on the wavelength. With increasing wavelength the penetration depth is also increasing and reaches a maximum at about 1000 nm.[12]

So far the effect of spot size on the efficacy of laser-assisted hair removal is unclear. Ort and Anderson[7] suggested an optimal spot size of 10 mm or larger, regardless of which laser is used. Tan et al.[10] showed in an experimental setting using a flashlamp-pumped dye

laser that with a larger spot size the depth of the thermal injury is increased. Littler[11] reported that the transmittance of light in tissue is increased by nearly 15% when the spot size of a diode laser at 810 nm is raised from 8 to 12 mm. However, the exact penetration depth of light into skin in vivo at 810 nm is unknown but should be in the range of 2–4 mm.[11,14]

In our setting, 1 month after treatment the growth delay (Figure 3) was markedly improved by increasing the spot size from 8 to 12 mm. This is mainly due to an increased penetration depth caused by the larger spot size. The growth delay was comparable using a spot size of 12 or 14 mm. The optical transmittance measured for both spot sizes (12 and 14 mm) by Littler[11] shows comparable values.[11] There was no significant difference in the growth delay regarding the spot size after 3 months.

The fluence applied was reduced from 44 J/cm^2 (8 mm) to 40 J/cm^2 (12 mm), or 33 J/cm^2 (14 mm). Using large spot sizes, the light intensity in the upper part of the skin (about 0.5 mm) exceeds the intensity applied to the skin surface.[15] Therefore the fluence is usually lowered with increasing spot size in order to avoid side effects in the epidermis and the upper dermis.

The selective thermal destruction of a target by light is described by the principle of selective photothermolysis.[6] The energy is applied at a wavelength well absorbed by the target, within a time period less than or equal to the thermal relaxation time of the target. When using a diode laser for hair removal, part of the light energy is absorbed in the melanin of the epidermis. Therefore the laser pulse in our study was divided into two pulses of 60-msec duration with a delay of 40 msec. With a thermal relaxation time of the epidermis of about 10 msec,[7] a break of 40 msec is used for sufficient cooling of the epidermis. Since the aqueous gel on the epidermis has a high heat capacity and a fast heat conductivity it is reasonable that the main part of the heat is conducted into the gel. The thermal relaxation time of a terminal hair follicle with a diameter of 200–300 μm is estimated to be 40–100 msec.[7] The duration of one pulse is sufficient to heat up the follicle. After cooling the epidermis (40 msec) the temperature inside the follicle starts to decrease. However, the second pulse continues to heat the follicle for a further 60 msec, leading to selective damage of the follicle. The low rate of side effects and high efficacy of the double-pulsed diode laser used in this study confirm these suggestions. In addition, the selective damage of the hair follicle using the double pulses is validated by the histologic findings. In all volunteers the epidermis was unaltered 24 hours after the treatment, whereas the follicle was destroyed.

The pain during laser treatment was comparatively low as indicated by the value of less than 1 on the analog scale of 0–10. In contrast, when using a ruby laser (694 nm, 12 J/cm^2) with an identical handpiece (Figure 1) the value was 3.2 ± 2.2 (unpublished data). The diode laser (810 nm) exhibits reduced absorption in the epidermis as compared to the ruby laser and no absorption in water as compared to the Nd:YAG laser. Therefore the damage and consequently the induction of pain should be almost completely restricted to the hair follicle.

Due to the decreased absorption of light in melanin at 810 nm the efficacy of laser-assisted hair removal is correlated to the color of the hairs, as shown with the 8 mm spot size. After treatment the diameter of the regrowing hairs decreased, as shown by Lin et al.[16] When evaluating the regrowth 15 months after the last treatment, the long-term efficacy of the double-pulsed diode laser was clearly demonstrated. Nine of 16 volunteers showed a visible reduction of hair.

The present study provides evidence of effective and long-term hair removal using the diode laser with appropriate laser parameters such as spot size, fluence, and pulse duration.

References

1. Bjerring P, Zachariae H, Lybecker H, Clement M. Evaluation of the free-running ruby laser for hair removal. A retrospective study. Acta Derm Venereol 1998;78:48–51.
2. Goldberg DJ, Ahkami R. Evaluation comparing multiple treatments with a 2-msec and 10-msec alexandrite laser for hair removal. Lasers Surg Med 1999;25:223–8.
3. Campos VB, Dierickx CC, Farinelli WA, Lin TY, Manuskiatti W, Anderson RR. Hair removal with an 800-nm pulsed diode laser. J Am Acad Dermatol 2000;43:442–7.
4. Goldberg DJ, Samady JA. Evaluation of long-pulsed Q-switched Nd:YAG laser for hair removal. Dermatol Surg 2000;26:109–13.
5. Sadick NS, Shea CR, Buchette JL, Prieto VG. High-intensity-flashlamp photoepilation. Arch Dermatol 1999;135:668–76.
6. Anderson RR, Parrish JA. Selective photothermolysis: precise microsurgery by selective absorption of pulsed radiation. Science 1983;220:524–7.
7. Ort RJ, Anderson RR. Optical hair removal. Semin Cutan Med Surg 1999;18:149–58.
8. Nanni CA, Alster TS. A practical review of laser assisted hair removal using the Q-switched Nd:YAG, long-pulsed ruby and long-pulsed alexandrite lasers. Dermatol Surg 1998;24:1399–405.
9. Goldberg DJ, Silapunt S. Histologic evaluation of a millisecond Nd:YAG laser for hair removal. Lasers Surg Med 2001;28:159–61.
10. Tan OT, Motemedi M, Welch AJ, et al. Spotsize effects on guinea pig skin following pulsed irradiation. J Invest Dermatol 1988;90: 877–81.
11. Littler CM. Hair removal using an Nd:YAG laser system. Dermatol Clin 1999;17:401–28.
12. Patterson MS, Wilson BC, Wyman DR. The propagation of optical radiation in tissue II: optical properties of tissues and resulting fluence distributions. Lasers Med Sci 1991;6:379–90.
13. Raulin C, Greve B. Current status of photoepilation. Hautarzt 2000;51:809–17.
14. Haina D, Landthaler M, Braun-Falko O, Waidelich W. Comparison of the maximum coagulation depth in human skin for different types of medical lasers. Lasers Surg Med 1987;7:355–62.
15. Van Gemert MJC, Jacques SL, Sterenborg HJ, Star WM. Skin optics. IEEE Trans Biomed Eng 1989;36:1146–55.
16. Lin TY, Dierickx CC, Campos VB, Farinelli WA, Rosenthal J, Anderson RR. Reduction of regrowing hair shaft size and pigmentation after ruby and diode laser treatment. Arch Dermatol Res 2000;292:60–67.