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The removal of unwanted hair using a ruby laser

D. T. Gault, A. O. Grobbelaar, R. Grover, S. H. Liew, B. Philp, R. M. Clement and M. N. Kiernan

Department of Plastic Surgery, RAFT Institute for Plastic Surgery Research, Mount Vernon Hospital, Northwood, UK

SUMMARY. A ruby laser has been developed to remove unwanted hair. Melanin within the hair is used as a natural chromophore. It is postulated that photothermal damage destroys the hair itself and also key cells surrounding the hair follicle to prevent regrowth. A prospective study of laser depilation in 116 patients or 175 sites was performed over a period of 18 months. All the patients had tried other methods of hair removal and found them to be unsatisfactory.

Hair counts (follicles/cm^2) were used to judge the outcome. The mean follow-up time was 23.25 weeks (range 12–76 weeks). After a mean number of treatments of 1.92 (range 1–20) there was a 56.4% reduction in hair density. Comparing pre- and post-treatment hair density, there was a highly significant reduction (paired *t*-test: $P < 0.00001$).

Laser removal of hair is now a realistic treatment option.

Keywords: hair, depilation, ruby laser.

Hirsutism, the presence of excessive body hair, is extremely distressing to many patients. In most cases there is no obvious cause; some patients have a hormonal disturbance associated with polycystic ovaries. Excessive hairiness of the body or face affects approximately 10% of women between the ages of 18 and 35. Hirsutism is also a feature of the menopause in a number of women. Hirsutism causes considerable psychological distress and in many patients this prevents them from confidently integrating into society.

Unwanted hair may also present a problem in planning reconstructive surgery for large congenital naevi or on flaps transferred from a distant site. The use of the lower abdominal paunch in breast reconstruction, and the use of forearm tissue for intraoral lining, can sometimes carry with it an unwanted hair pattern. It is also possible that in some diseases, such as pilonidal sinuses, hair removal could assist in cure.

Hair biology

Hairs are dead structures of keratinised cells cemented together. They grow out of tubes of epidermis sunken into the dermis. Hair growth cycles continuously: growing follicles are said to be in anagen and quiescent ones in telogen; the period of transition between the two is known as catagen. After the growth phase (anagen) a large part of the bulb at the base disappears (catagen) and the remaining follicle enters the quiescent stage (telogen).[1]

The hair follicle consists of an outer root sheath, an inner root sheath and a hair at the centre. The hair itself comprises a central medulla surrounded by a cortex of fused keratinised cells, and covered by a cuticle of overlapping scales. In coloured hairs, melanin granules are located in the cells of the cortex.

Hair morphology varies greatly at different sites. Hairs can be long, short, thick, thin, coloured or white. The whole range of hair colour depends on two types of melanin: eumelanins are responsible for a black or brown hair colour, and pheomelanins (yellow and red pigments) for blonde and auburn colours.[2] A hair without any pigment looks grey or translucent.

Melanocytes in the upper portion of the hair bulb produce packets of pigment (melanosomes) which are included in the cortical and medullary cells of a hair. The outer cuticle and inner root sheath do not contain melanin. In black hair the melanin is uniformly dense within the melanosome. Lighter hair contains less melanin within each melanosome.

Currently available techniques for hair removal vary from shaving and depilation creams to waxing, sugaring, threading and electrolysis. Most of these techniques are temporary measures only. Although electrolysis is described as one of the more permanent solutions for unwanted hair, many patients find the technique slow and the results of repeated treatments can be disappointing. A treatment which is easier to administer with reliable results would have wide application.

Previous work has shown that the thermal energy from narrow beams of light directed at individual hairs can be used to effect destruction in a similar manner to the removal of hairs using electric cautery with fine needles. Argon lasers have been used to remove troublesome eyelashes.[3–6] Lasers have also been used to remove unwanted hair in hidden sites, e.g. the urethra or oesophagus.[7,8] In these techniques, hairs are treated one at a time, and the scarring kept to a minimum by heating each individual hair with a narrow beam of laser energy.

In order to treat a number of hairs simultaneously, it is necessary to enlarge the spot size. A technique

which selects out hairs, destroying the hair follicle and outer root sheath only, is required if damage to surrounding skin is to be avoided. This study seeks to demonstrate that laser light can be used in such a selective fashion to remove unwanted hair. Lasers are commonly used to destroy coloured lesions – port wine stains, tattoos or pigmented lesions – whilst inflicting little damage on the background skin. In these instances, laser light is targeted towards a specific chromophore in the skin responsible for the colour of the lesion, e.g. haemoglobin, tattoo inks and melanin, so that it selectively absorbs the energy whilst leaving other skin components undamaged.[9] In this study, melanin within the hair has been selected as the target chromophore, and it is postulated that when sufficient energy is deposited there, then damage is inflicted on key cells adjacent to the hair.

Dermal tissue is capable of inducing new hair follicle formation only in the foetus, and if the stem cells responsible for hair growth can be destroyed, then the treatment should effect a permanent solution. The stem cells have been assumed by many to be located in the hair bulb[10–12] which often protrudes beneath the dermis and can lie up to 5 mm beneath the skin surface. Recent work by Cotsarelis et al,[13] however, has suggested that they may reside in a bulge zone in the mid-shaft area. This idea is based upon experimental evidence showing radio-labelled cells with a slow turnover in the outer root sheath at the level of the bulge (where the erector pili attach). The slow-cycling nature of the stem cells is one of their most distinguishing features.[14] The concept that stem cells are located high up in the hair shaft is in keeping with the observation that a follicle can regenerate after the hair bulb is removed surgically.[15,16] This region is also permanently retained throughout the hair cycle, while the bulb protruding below the dermis is not retained in the catagen phase.

This so-called bulge activation hypothesis is a useful concept, but is nevertheless controversial.[17,18] More recent work has shown that cells in the follicle below the bulge zone and above the hair bulb have the expected properties of stem cells.[19] Assuming, however, that the target zone for laser destruction is closer to the skin surface than the bulb, in theory, in both children and adults, selective destruction of the hair follicle epidermis in the mid-shaft area should prevent hair regrowth.

The need for light to penetrate the skin to a required depth was a key factor in choosing a laser system. An examination of the skin penetration profiles showed that maximum skin penetration was achieved in the red area of the spectrum, with minimum absorption of the energy by blood. Some 8 years ago, one of the authors (RMC) made the chance observation that after free-running ruby laser light inadvertently struck his forearm, hair did not grow again in the affected area. Similar laser parameters were chosen for trial work.

In order to gain a better understanding of laser–tissue interaction, a theoretical computer model incorporating the thickness, absorption coefficient and scattering coefficient of the epidermis, basal layer and dermis was used to provide a temperature profile within a hair shaft treated with ruby laser light.

Using the ruby laser in the free-running mode at a wavelength of 694.3 nm (pulse duration 100–500 μs), it was predicted that the peak temperature within the hair shaft would reach 180°C. The temperature of cells in the bulge zone is raised through conduction of heat and was predicted to rise to 70°C for 800 ms. If the pulse duration was to rise above 2 ms then the skin structures surrounding the hair follicles could be damaged.[20] A pulse duration of 600 μs was predicted to destroy hair without surrounding skin damage.

Previous work on the thermal destruction of port wine stains by pulsed dye laser radiation had shown that, to cause permanent damage to the blood vessels, the temperature of the endothelial wall should rise to 70°C and be maintained for 1 ms. If this is also the case for hair follicle cells in the bulge region, then the model predicted that the laser parameters chosen are likely to be effective. The model also predicted that the skin surface temperature is not significantly affected by the laser pulse, therefore reducing any possible damage to the epidermis. These criteria do not, however, apply when the skin is darkly pigmented. In such cases skin absorption will be greater and there is a greater potential for unwanted side effects.

A prototype ruby laser was assembled to emit light at 694.3 nm. The energy output ranged between 5 and 25 J/cm^2 with a spot size of 5 mm diameter and pulse duration between 100 and 800 ms. Initial treatment on the forearms of workers on the project showed a slowing of hair growth compared to control sites without dermal scarring. Animal experiments on five anaesthetised Dark Agoutie rats showed that at energy densities of 6–10 J/cm^2 hair growth was reduced at 14 days, but there was little difference between lasered and control sites at 21 days. The hairs in these animals are dark at the tip (eumelanin) with a pale yellow section (pheomelanin) in the mid-portion of the shaft.[21]

A more marked impairment of hair growth was seen at higher powers (19–25 J/cm^2), but once again at 4 weeks, control and treated sites were similar. This preliminary work showed that hair growth could be slowed, but the predicted bald areas did not occur. The laser has no effect on white rats.

Q-switched ruby lasers are widely used to treat tattoos, but hair removal does not occur at the treated sites. The use of the ruby laser in free-running mode, however, was predicted to impair hair growth. A prospective trial of the laser to treat patients complaining of unwanted hair was therefore proposed with Ethical Committee approval.

Materials and methods

One hundred and sixteen patients with unwanted hair were treated with a flashlamp-pumped pulsed ruby laser (Model Chromos 694 QD, made by SLS Wales Ltd, Llanelli, UK) with the following output parameters:

Wavelength	694.3 nm (red light)
Pulse duration	600 μs
Energy density	0–30 J/cm^2
Spot size	5 mm diameter
Repetition rate	1 Hz maximum

Table 1 Skin types in study population

Skin type	*Description*	*No. of patients*
I	Always burns, never tans	25
II	Always burns, sometimes tans	40
III	Sometimes burns, sometimes tans	29
IV	Never burns, always tans	5
V	Asiatic peoples, moderately pigmented	14
VI	Black	3
	Total	116

In the study group were 25 males and 91 females, whose ages ranged between 2 and 61 years with a mean of 32.7 years. All the patients had undergone previous treatment for excessive hair without success. Some patients had developed an allergy to depilatory creams, some found waxing led to the development of infected ingrowing hairs, and some patients had scars and pigment changes after electrolysis or plucking.

The majority of patients had hirsutism of unknown aetiology, but in a small number of patients a specific cause of the unwanted hair was identified: 18 had polycystic ovaries; eight had some unwanted scalp hair draped over a cartilage framework following an ear reconstruction; one had developed excess hair following a burn; one grew excess hair in a zone treated by radiotherapy; and three had had large-diameter punch grafts added to a receding hair line and had then found the tufted appearance of the graft an embarrassment as further recession occurred.

A variety of treatment sites were chosen: scalp, face and chin, arms, chest, axillae, legs, abdomen, back, penis (after removal of excess foreskin during circumcision) and the natal cleft. In some early patients, Emla cream was applied prior to treatment, but most patients found this unnecessary. Without analgesics, a mean pain score of 1.26 out of a possible maximum of 10 was given for the treatment (range 0–8).

At the first treatment sessions, a test patch between 2 and 5 cm in diameter was treated. Test patch sites were chosen to be inconspicuous. On the face, a small area beneath the chin or in front of the ear was usually chosen.

Energy densities varied between 8 and 25 J/cm^2. The power was adjusted until surface hair destruction was seen. Hairs would jump, bend or smoke, and often would completely disappear. The laser pulse was applied evenly throughout the treatment site with some overlapping of the shots. The number of pulses delivered at each treatment session varied between 3 and 1064. Hair was trimmed or shaved to leave approximately 1 mm showing above the skin surface prior to treatment. (It is important not to pluck or wax the hair shortly before treatment as this would remove the intended target from the hair follicle.)

Where there were no unwanted side effects after a test patch and where the results appeared favourable, then a further more extensive treatment was offered. The results were recorded by close-up photography, but a more reliable guide was found to be the counting of hairs within 1 cm^2 using a magnifying grid. Aloe Vera gel was applied to the treatment site following the laser treatment. Patients were advised to avoid exposure to strong sunlight after treatment to minimise the chances of hyperpigmentation at the treatment site.

The interval between treatment and review varied. Hair counts per square centimetre were recorded at follow up visits. Of the 116 patients in the study, 46 had black hair, 38 had brown hair, 29 had blonde hair and three had red hair. The majority of people in this study had little melanin within the epidermis (skin types I–IV), see Table 1.

Results

The mean hair density prior to treatment was 23.98/cm^2 and that after treatment was 11.63/cm^2. The mean reduction in hair density of 56.4% was shown to be significant using a paired *t*-test ($P < 0.000001$). Follow-up ranged between 12 and 76 weeks, with a mean of 23.25 weeks. The mean number of treatments was 1.92 (range 1–20). Gender, age, site or aetiology did not appear to influence the results.

Only 20 sites showed no response. Fifty-eight sites were followed up for 24 weeks or more. In this group, the mean hair density prior to treatment was 24.6/cm^2 and following treatment it was 13.02/cm^2. The mean reduction in hair density was 51.8% (paired *t*-test analysis: $P < 0.00001$). In this group the mean number of treatments was 2.16 (range 1–20).

On viewing the results treated above and below the mean power of 15.6 J (86 sites), the percentage hair reduction above the mean was 55.2% and the percentage hair reduction below the mean 57.9%. This was not statistically significant (Student's *t*-test, $P = 0.57$).

Hair colour appears to be important. The mean reduction in hair density post-treatment was 60.97% in brown and black hair compared to 55.92% in white hair. This difference was statistically significant (multiple ANOVA, $P < 0.0118$).

After laser impact, dark hairs fragmented readily. In patients with a mixed growth of dark and grey hairs, the treatment abolished the dark hairs, but left the grey hairs behind. Patients commented that where fragments of dark hairs were left in the laser-treated zone they readily fell out several days later. Usually no immediate skin change was seen, but in black patients blistering was observed and in several patients the skin was red for approximately 12 h. No bruising was seen. In four patients, hyperpigmentation of the skin was seen after treatment. Hypopigmentation was seen in two patients.

In no instance did scarring result, and for those patients in whom ingrowing hairs were the primary problem, the treatment was particularly successful. Presumably, the density of chromophore afforded by hairs coiled up within the skin proved to be an ideal target for the laser. In those patients where treatment did not reduce the hair density, the patients sometimes commented that the hairs were finer, softer and grew at a slower rate after treatment.

Discussion

Laser hair depilation has been used to treat trichiasis,[4–6] remove unwanted hair from grafts[7,8] and, more

recently, the principle of selective thermolysis has been used to depilate human volunteers.[22] Photodynamic therapy using aminolevulinic acid has been used to destroy hair[23] and application of a carbon particle suspension followed by removal from the skin surface and exposure to a Q-switched Nd:YAG laser has also been used.[24] Grossman et al reported their experience using the ruby laser in 13 volunteers.[22]

Ruby laser treatment of 116 patients at the described parameters has resulted in a significant reduction in hair follicle density. No scarring was seen, but in some patients (3.4%) pigmentation changes occurred, and it is recommended that a small trial zone or test patch be treated initially to assess both the effectiveness of treatment and the likelihood of skin pigmentation changes.

Multiple treatments of the same area are required to treat tattoos and port wine stains with laser therapy, and it is likely that multiple treatments will give improved results with a depilatory laser. It is important that all laser treatment is carried out in an approved location with a secure door and protective eye wear for patients and staff.

Good results in those patients treated at lower powers may reflect an increased sensitivity of their hair to photothermal damage. Higher powers were applied only in those patients in whom the hair appeared at treatment to be resistant to laser treatment. This was often the case with hair on the point of the chin. Other studies have suggested that a low damage threshold for induction of growth delay and a higher damage threshold for permanent hair loss is necessary.[21]

Extreme caution is recommended in treating patients with brown and black skin. It is important to begin the test patch at very low powers (8 J/cm^2) and to increase the power slowly until laser destruction of visible hair is achieved. Certainly, the power should be kept lower than that which causes skin blistering. Test patches should be small and in inconspicuous sites. The more pigment in the epidermis, the greater the absorption of the laser energy by that layer. Skin complications of blistering, hypopigmentation and hyperpigmentation were seen only in patients with skin types V and VI. In these patients, less energy is available to reach a target within the epidermis. Epidermal pigmentation has been shown to adversely affect the ability of pulsed dye lasers to treat vascular lesions.[25]

Two further points are worthy of mention. The mean reduction in hair density in those patients with the longest follow-up was well maintained, and these patients had the largest number of treatment sessions. Those patients who had a poor response, however, often did not attend for long-term follow-up, and cannot be included in that group.

Finally, the interaction between ruby laser light and the melanin within a hair has been assumed to be photothermal. Some authors have, however, shown that light can interact with melanin to produce free radicals and it is possible that this mechanism may also contribute to hair destruction.[26–28] This initial study is the first step in a series of research projects to treat hirsutism. Further refinements and guidelines are inevitable.

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The Authors

D. T. Gault FRCS, Consultant Plastic Surgeon,
A. O. Grobbelaar MMed(Plast), FCS(SA), FRCS(Plast), Consultant Plastic Surgeon,
R. Grover MD, FRCS, Registrar in Plastic Surgery,
S. H. Liew FRCS, Research Fellow,
B. Philp FRCS, Research Fellow,

Department of Plastic Surgery, RAFT Institute for Plastic Surgery Research, Mount Vernon Hospital, Rickmansworth Road, Northwood, Middlesex HA6 2RN, UK.

R. M. Clement, Professor in Optoelectronics, Faculty of Design and Engineering, Swansea Institute of Higher Education, Swansea, UK.

M. N. Kiernan, Development Manager, SLS Biophile, Llanelli, UK.

Correspondence to A. O. Grobbelaar, Department of Plastic Surgery, Mount Vernon Hospital, Rickmansworth Road, Northwood, Middlesex HA6 2RN, UK.

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