# Q-switched ruby laser treatment of tattoos; a 9-year experience

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Summary—Nine years of clinical experience of the application of the Q-switched ruby laser to the removal of tattoos is presented. This laser achieves optimal removal of blue/black amateur tattoos by its selective interaction with the dermal suspensions of pigment which constitute the tattoos. The scarfree cosmesis thus achieved is a considerable improvement on non-specific laser techniques whereby the laser is absorbed to a comparable degree in both pigmented and non-pigmented tissue. Long-term results are analysed and it is noted that a variety of professional tattoos may also respond to treatment. The mechanisms and appearance are discussed and correlated with short-term healing processes.

It is found that power densities in the range 1200–2800 GW/m² are most suitable. Appropriate dosimetry can be witnessed by the appearance of opaque intradermal vacuoles corresponding to the vapourisation of the tissue water surrounding the pigment suspensions.

Treatment by Q-switched ruby laser offers a viable scar-free option for a wide range of dark tattoos, leading to a more acceptable clinical outcome in most cases than other current therapies.

A number of laser therapy techniques have been proposed for the removal of unwanted tattoos. Many of these induce localised burning of the tissue by an unselective targeting of the tattooed site (Reid and Muller, 1978). Carbon dioxide, argon and Nd:Yag lasers have all been used in this application. While offering to many of those inflicted a desirable option, the cosmesis is generally unacceptable, with scarring resulting in many cases.

An alternative technique targets the pigment as a chromophore within the translucent dermis. This requires a judicious choice of wavelength and pulse width to ensure selective absorption of the optical radiation and confinement of the thermal energy by the targeted pigment.

In order that competitive absorption by the epidermal melanin be minimised, a wavelength towards the red end of the visible spectrum is desirable. This precludes the removal of red pigments by direct selective absorption, although other mechanisms can be invoked. Consequently, earlier reports describe only the removal of blue/black tattoos (Goldman, 1967; Reid *et al.*, 1983).

While appropriate choice of wavelength ensures optimal absorption within target structures, laser exposure duration dictates the extent of the local confinement of the heating effect produced. Subse-quent damage may then be of a thermal or mechanical nature. If the energy is delivered in a time less than the "cooling time" of the optical target, conduction is minimised and local temperature rise is higher. This may lead to an explosive reaction.

A mechanical process is thought appropriate to the disturbance of the enclosed pigment suspensions whereas thermal damage, commonly associated with the application of a continuous wave emission, would tend to produce shrinkage of the surrounding dermis, with no obvious beneficial pigment dispersal. Indeed, the encapsulation might be reinforced.

For selective effect on tattoo ink, and subsequent tissue repair, it is vital that the wavelength and pulse width are appropriate to the induction of selective absorption, followed by minimal conduction, leading to localised mechanical interaction. The ruby laser in Q-switched mode offers such a modality. Prior studies (Reid *et al.*, 1983) have investigated the treatment of black tattoos using this laser. When Q-switched, a maximum energy of 3 J in a 30 ns pulse may be attained. This pulse width is within the thermal retention time of even the smallest pigment clusters which constitute the tattoo and hence will induce minimal thermal damage to the surrounding tissue. Excellent results

have been reported in the treatment of blue/black tattoos, although multiple exposures have been found to be necessary in many cases (Reid *et al.*, 1983).

This study collates a 9-year experience of the treatment of tattoos using the Q-switched ruby laser. Clarifications of mechanisms and damage thresholds are presented and new observations concerning the response of multi-coloured tattoos discussed.

## Materials and methods

A Q-switched scientific ruby laser (manufactured by JK Lasers) was used in these trials. Q-switching provides a means by which nanosecond-domain pulses of high individual energies may be produced from certain host materials.

This produced pulse energies of up to 3J with pulse widths of 30ns, at a wavelength of 694nm. An articulated arm was used to deliver the high peak powers to the treatment site. This arm used prisms to deflect the beam through a plano-convex focusing lens to a spot size of 5 mm incident on the skin. The pulse energy passing through this 5 mm aperture was measured using a Scientech model 365 energy indicator with a black body response. The pulse-to-pulse stability of the laser was 10%.

### Subjects

Over a 6-year period, following the *in vitro* trials (Ritchie, 1982), 418 patients were treated (Tables 1 and 2). All were fair Caucasians with no known history of cutaneous disease. Of these, a total of 341 had amateur or self-inflicted tattoos while 75 had professionally-applied tattoos. A range of tattoo sites was treated, including arms, neck, head and chest.

### Methods

A local anaesthetic (1.0% lignocaine) was injected subcutaneously to all patients prior to exposure. The laser pulses were then manually directed onto the skin by means of the articulated arm and overlapping 5 mm exposures induced at intervals of several seconds.

In each patient an energy was found corresponding to the onset of whitening. Earlier studies had linked this with the formation of vacuoles in the dermis due to the production of steam (Ritchie, 1982). Patients were recalled at intervals of 3–4 weeks for additional exposures, this having been previously identified (Reid *et al.*, 1983) as the

**Table 1** Patient results, amateur tattoos (December, 1989)

| | | |
|---|---|---|
| No. of tattoos treated | 341 | (100%) |
| No. of completed treatments (<10% pigment remaining) | 191 | (56%) |
| Mean no. of treatments required | 4.92 | |
| Standard deviation | 2.4 | |
| No. of ongoing treatments | 118 | (35%) |
| No. with <50% pigment remaining | 50 | |
| No. with >50% pigment remaining | 68 | |
| Mean no. of treatments | 3.5 | |
| No. of discontinued treatments | 32 | (9%) |
| Reason for discontinuation: Inconvenience (*e.g.* travel) | 21 | |
| Medical advice (*e.g.* hyperpigmentation) | 11 | |

minimum period for effective fading of the whitening. A number of exposures of the same treatment site was found to be necessary in all cases. Biopsies were obtained in a number of patients and long-term dermal/epidermal response monitored (Newstead, 1988).

## Results

Clinical response was recorded after exposure and prior to each repeat treatment. Most subjects experienced a pinprick sensation when the threshold was reached, accompanied by a blanching of

**Table 2** Patient results, professional tattoos (December 1989)

| | | |
|---|---|---|
| No. of tattoos treated | 77 | (100%) |
| No. of ongoing treatments | 68 | (91%) |
| No. of completed treatments | 2 | |
| No. with 50%–80% pigment removal | 16 | |
| Mean number of treatments | 4.56 | |
| No. with 0–50% pigment removal | 52 | |
| Mean number of treatments | 2.4 | |
| No. of discontinued treatments | 7 | (9%) |
| Reason for discontinuation: Inconvenience (travel) | 4 | |
| Medical advice (*e.g.* hyperpigmentation) | 3 | |

the pigmented site. This blanching persisted for a period of several hours after treatment. In addition, a number of patients experienced hypo- or hyper-pigmentation of the treated site, which was recorded on their subsequent visit.

The treatment of 418 tattoos is recorded. The mean duration of laser treatment was approximately 12 minutes. Both amateur, or "self-inflicted", and professionally-applied tattoos were treated although the treatment of many more amateur than professional tattoos was attempted in the earlier stages of the study. Consequently the number of "completed" professional tattoos at the time of writing is substantially less.

The results documenting the treatment of 341 amateur tattoos are presented in Table 1. Treatment is judged to be complete if less than 10% of the pigment remains. Treatments are then terminated. A good result is related to the subjective identification of 50–90% removal of pigment, following which repeat irradiations may be administered in order to complete the course of treatments.

The spread around the mean of 4.92 shown in Table 1 is large, with requirements varying from 2 to 12 treatments to effect removal. Such a removal is associated with a normal, scar-free cosmesis (Figs 1 and 2).

The statistics relating to ongoing treatments identify the achievement of a "good" result in 50 of the 188 patients after a mean number of 3.5 treatments. Such patients might reasonably be expected to progress to completion after a mean additional 1.42 treatments.

A number of patients (9%) discontinued during treatment for personal reasons or due to the onset of a degree of hyperpigmentation at the treatment site. Subsequent to the induction of hyperpigmentation, treatment was discontinued pending the results of histological and cytogenic studies (Ritchie, 1982). Occurrence of mild hypopigmentation was common although difficult to quantify due to the fair skins of many of the subjects originating from the West of Scotland.

A total of 77 professionally-applied tattoos was treated in addition to the 341 amateur tattoos. Histologically such tattoos are similar (Figs 3 and 4), consisting of collagen-enclosed dermal capsules, although professional tattoo pigment is generally more evenly distributed to a higher density.

All of the professional tattoos treated were principally blue/black although many contained traces of brighter colours. These additional colours were not irradiated directly. The treatment of professional tattoos was a more recent development from the earlier trials of amateur tattoos; consequently, of the 77 treated, 68 were still undergoing treatment at the time of writing, only two having had 100% pigment removal.

Of the ongoing treatments of the professional tattoos, a "good" result has been achieved in 16 of the tattoos, having had a mean of 4.56 treatments. This compares with the two completed professional tattoos having had 6 and 7 treatments respectively (Figs 5 and 6). The remaining 52 tattoos were insufficiently far advanced in their course of treatments to exhibit greater than 50% fading, having had a mean of only 2.4 treatments. A small proportion (approximatley 9%) of patients were forced to discontinue treatment for personal or medical reasons.
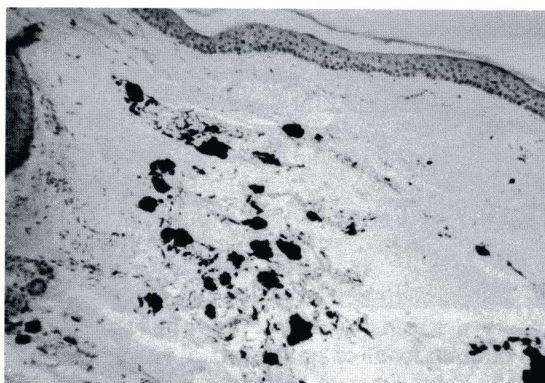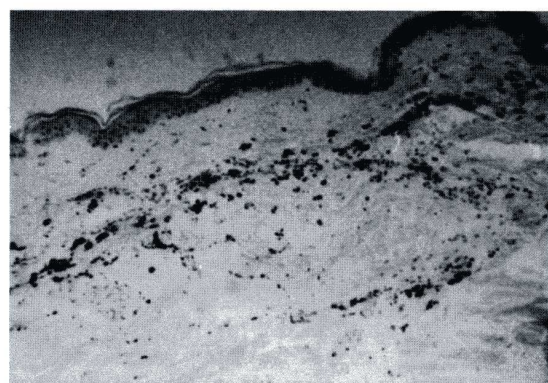


Fig. 3



Fig. 4

Figure 3—Histological section of amateur tattoo. The irregular size and distribution of the pigment clusters can be clearly seen (×150). Figure 4—Histological section of professional tattoo (unstained) (×100).

Many of the dark professional tattoos had areas of red and green pigment which, although not irradiated directly, were found to fade considerably in response to the treatment of neighbouring sites (Figs 7 and 8).

## Discussion

Pigment removal occurs as a two-stage process. In stage one, large temperature gradients are induced in the vicinity of the pigment clusters, leading to an explosive interaction which breaks apart the clusters. In stage two, physiological defence mechanisms are subsequently invoked to dispose of the debris.

The 694nm wavelength emitted is highly absorbed by the dark dermal pigment suspensions while the short pulse width of energy, within the thermal retention time constant of the clusters, is effectively retained by the target site. A rapid increase in temperature is then achieved which causes disruption of the collagen-enclosed pigment particles by vapourisation of the surrounding tissue water. Calculations show that carbon dioxide may also be produced (Ritchie, 1982) following a reaction with the carbon-based pigment. Evidence suggests that physical expansion of the site produces rupture of the collagen matrix followed by a shock wave. Fragmentation of the rigid pigment particles then occurs as a result of interaction with the shock wave. The smaller remaining pigment clusters may then be removed through the process of phagocytosis, whereby macrophage activity transports the scattered pigment away from the site of suspension. During this 1 to 3-week period any localised damage associated with the rupture of the collagen is repaired.

A number of repeat treatments is found necessary to remove the remaining pigment completely (Tables 1 and 2). This is a consequence of the scattered nature of the pigment suspension within the dermis whereby a non-uniform depth distribution ensures a partial shadowing of the deeper clusters by the superficial "layers". The repeat treatments are optimally spaced by the "healing" period of the dermal matrix (1–3 weeks), while the skin physiology is allowed to return to normal.

The results (Tables 1 and 2) suggest a mean requirement of 4.92 treatments to effect removal of an amateur tattoo, while the ongoing study of the removal of professionally-applied pigment would seem to entail an additional requirement of 1–2 sessions. These observations may be related to the density of pigment being higher in the case of professional tattoos than that found in the "typical" amateur tattoo. The nature of the chemical compound may also be of importance and is presently under study.

A number of the treated sites (approximately 3%) exhibited signs of hyperpigmentation (Fig. 9) and treatment was discontinued, although normal skin appearance resumed after several weeks. Hypopigmentation, associated with the removal of melanin from the epidermis above the treated site, was more commonly observed in highly tanned patients and was found to persist for a number of weeks. Such subjects were cautioned to avoid direct exposure to sunlight while the whitened appearance remained (4–8 weeks).

A long-term study (Newstead, 1988) found no evidence of mutagenicity associated with any of these observations. In none of the patients followed were instances of atrophic or hypertrophic scarring observed.

Several of the professional tattoos which were treated contained red and green colouration which was observed to fade substantially during the course of treatments, although not directly irradiated. Such colouration only faded when a surrounding area of dark pigmentation was treated. The subsequently enhanced phagocytotic response which appeared to be produced had affected both treated and untreated sites to a similar extent, leading to a fading of colours which might otherwise not have been expected to respond to treatment on account of their low absorption at the laser wavelength of 694nm.

In summary, both amateur and professional tattoos responded favourably to treatment by Q-switched ruby laser. This laser, when traced over dark pigmented areas, induced a gradual fading in the irradiated site, accompanied by an additional fading of any surrounding lighter pigment.

Major technical advances have recently been made in the laser and delivery equipment, facilitating its use clinically and minimising inconvenience to the patient. These advances include the development of an articulated delivery system enabling highly efficient and reliable coupling of the laser energy onto the treatment site. Large areas may then be treated within a small time period. Thus, Q-switched ruby laser treatment has been shown to be eminently suited to the removal of dark amateur tattoos. In addition, present studies strongly indicate the efficacy of this technique for the removal of dark tattoos of the professional variety.
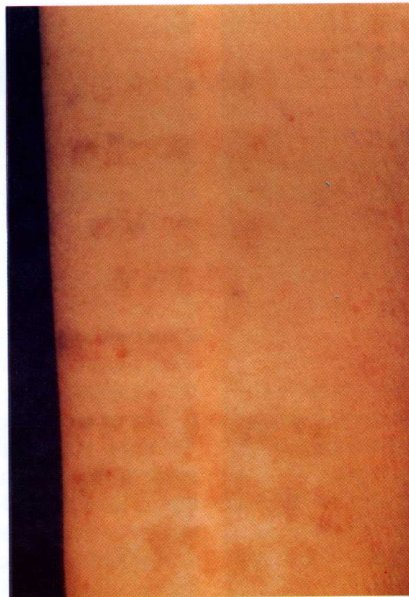
Fig. 7



Fig. 8



Fig. 9

**Figure 7**—Professional tattoo containing red pigment, before treatment. **Figure 8**—Professional tattoo during treatment (after four exposures). **Figure 9**—Hyperpigmentation following treatment of amateur tattoo.

## Acknowledgements

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