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# Invited Review
# Q-switched Laser Treatment of Tattoos

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**Abstract.** In the last decade, Q-switched lasers have expanded the clinician's ability to treat decorative, cosmetic and traumatic tattoos without scarring. Previous methods of gross tissue removal with resultant scarring have been replaced by the highly selective removal of tattoo pigment with minimal changes in skin texture or pigmentation. This article reviews use of the Q-switched ruby, Q-switched neodymium–yttrium-aluminum-garnet and Q-switched alexandrite lasers in the clinical management of patients with tattoos.

## INTRODUCTION

Between 5 and 10% of the adult population have a tattoo for either decorative or cosmetic purposes or as a result of trauma or medical treatment. The word *tattoo* is derived from the Polynesian (Marquesan) word *tatu*, and refers to the accidental or volitional acquisition of pigmented particles in the skin. A wide variety of agents and techniques have been tried over the years to remove tattoos, but none has proven entirely satisfactory. Previously popular methods of removal included excision with primary closure or skin grafting, mechanical dermabrasion, salabrasion, cryosurgery, application of caustic chemicals such as phenol, or a combination of the above, all of which habitually leave noticeable scars which, depending on the anatomical location, could be hypertrophic or keloidal. Most patients accepted treatment only because the stigma of the tattoo was of greater social hindrance than the scarring.

Both argon and carbon dioxide lasers have been used to treat tattoos (1–3). Successive layers of skin are removed to expose the pigment, which is subsequently vaporized, and the wound is allowed to heal by re-epithelialization from adjacent skin and undamaged dermal appendages. However, because there is no colour-selective light absorption, non-specific thermal damage to adjacent dermal structures occurs and, therefore, virtually all patients have some form of secondary scar formation.

## SELECTIVE PHOTOTHERMOLYSIS

The laser has many inherent physical properties that contribute to its ability to effect a specific biological outcome. Most importantly, from a clinical point of view, are the properties of emitted wavelength and pulse duration of light exposure. If the clinical objective is to cause selective destruction of a specific chromophore within the skin, the wavelength chosen should match the absorption peak of the targeted molecule relative to other optically absorbing structures. Wavelength also determines the depth to which light will penetrate with sufficient energy density to effect tissue change. Amorphous carbon, graphite, India ink and organometallic dyes, typically found in dark blue-black amateur and professional tattoos, have a broad absorption in the visible portion of the spectrum. Due to the absorption of light by haemoglobin and melanin, if the skin is irradiated with wavelengths in the 400–600 nm region, significant damage to the dermis will occur. However, at longer visible wavelengths (greater than 600 nm), absorption by haemoglobin will be minimal and absorption by melanin will be

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decreased (4, 5). Therefore, using longer visible wavelengths should permit more energy to be absorbed by the targeted tattoo pigment in the dermis, with less absorption by, and potential damage to, haemoglobin- and melanin-containing cutaneous structures.

Given that one goal of treatment is the precise control of thermal energy, the pulse duration of laser irradiation is just as important as optical and tissue factors. One way to maximize the spatial confinement of heat is to use a short pulsed laser with a pulse duration of the same order of magnitude as the thermal relaxation time ($T_r$) of the target chromophore (6). $T_r$ is defined as the time required for the temperature generated by the absorbed energy within the target chromophore to cool to one-half of its original value immediately after the laser pulse. During a lengthy laser exposure, most of the heat produced diffuses away, despite its origin in the target structure. The target will not become appreciably warmer than its surroundings since the absorbed energy is invested almost uniformly in heating of the target tissue during exposure. As a result, longer pulse durations offer a more generalized heating and, therefore, less spatial selectivity, resulting in non-specific thermal damage to adjacent structures, regardless of how carefully one has chosen the wavelength. However, if the laser pulse is suitably brief, its energy is invested in the target chromophore before much heat is lost by thermal diffusion out of the exposure field. A maximum, transient temperature differential between the target and adjacent structures will then be achieved. Shorter pulse durations confine the laser energy to progressively smaller targets with more spatial selectivity. The transition from specific to non-specific thermal damage occurs as the laser exposure equals and then exceeds $T_r$. Therefore, selective target damage depends on delivering a light pulse of shorter duration than $T_r$. $T_r$ can be estimated since the latter is directly proportional to the squared diameter of the target, and inversely proportional to the thermal diffusivity of the tissue. A laser emitting at a selectively absorbed wavelength with a pulse duration less than $T_r$ can be expected to cause highly selective target damage.

## Q-SWITCHED LASERS

Q-switching of lasers is a mechanism often used to control the light output by concentrating all the energy into a single, intense nanosecond pulse with extremely high peak powers (greater than $10^6$ W cm$^{-2}$). A fast electromagnetic switch (Pockel's cell) in the laser cavity causes excitation of the active medium to build up far in excess of the level obtained when the shutter is open. In operation, the flashlamp is turned on and the population inversion gradually grows; lasing is prevented by the shutter. When the population inversion is at a maximum, the shutter is opened so that lasing occurs and a large burst of energy is emitted as the cavity rapidly depletes the population inversion. The net result is a brief intense nanosecond pulse or series of pulses (7).

The calculated thermal relaxation time for 0.5–100 $\mu$m diameter granules of pigment, characteristically found in most amateur and professional tattoos, is approximately 20 ns to 3 ms (6). As a result of matching the pulse duration of laser exposure with $T_r$ of the targeted pigment granule, Q-switched lasers at longer visible wavelengths (greater than 600 nm) can produce selective destruction of tattoos without non-specific damage to adjacent skin structures. The Q-switched ruby laser (QSRL) was the first system to accomplish this objective, followed by the Q-switched neodymium–yttrium-aluminum-garnet (QSNd-YAG) and alexandrite (QSAlex) lasers. This article reviews use of these Q-switched lasers in the clinical management of patients with tattoos.

The QSRL (Table 1) is a solid-state laser containing a ruby crystal of aluminum trioxide doped with chromium (Cr) ions. Doping is a process in which the crystal is grown in the presence of an impurity so that the crystal lattice (aluminum trioxide) forms with the impurity (Cr) within it. A ruby rod is placed within the laser cavity where powerful flashlamps excite the Cr ions to produce red photons at a wavelength of 694 nm with 20–40 ns pulse durations. Laser energy is transmitted through an articulating arm which terminates in a microlens that focuses the radiation on a circular spot of uniform light intensity. The usual spot size is 4–6 mm with a pulse repetition rate of 0.5–1 Hz.

Q-switched ruby laser light penetrates about 1 mm into the skin and is extremely well absorbed by melanin and blue-black tattoo pigment. This deep penetration is clinically advantageous for reaching tattoo pigment in the dermis. Additionally, at a wavelength of 694 nm, the QSRL light is minimally absorbed

*Table 1.* Q-switched laser systems used in the clinical management of patients with tattoos

| Laser | Wavelength (nm) | Pulse width (ns) | Repetition rate (Hz) | Delivery |
|---|---|---|---|---|
| QSRL | 694 | 20–40 | 0.5–1 | Articulated arm |
| QSNd-YAG | 532, 1064 | 5–20 | 1–10 | Articulated arm |
| QSAlex | 755–760 | 50–100 | 1 | Fibre-optic |

QSRL, Q-switched ruby laser; QSNd-YAG, Q-switched Nd-YAG laser; QSAlex, Q-switched alexandrite laser.

by haemoglobin; it therefore falls within the previously defined therapeutic window for treating tattoos while avoiding vascular damage.

The QSNd-YAG laser (Table 1) is a solid-state laser containing a crystal of yttrium-aluminium-garnet (YAG) doped with neodymium (Nd) ions. A Nd-YAG rod is placed within the laser cavity where powerful xenon arc lamps excite the Nd ions to provide emission in the invisible near-infra-red spectrum at 1064 nm (1.064 $\mu$m) with 5–20 ns pulse durations. The longer wavelength of the QSNd-YAG laser allows deeper penetration (up to 4–6 mm), and although tattoo pigment absorption is poor, the light is preferentially targeted sufficiently to produce selective photothermolysis. In addition, the 1064 nm light interacts less with melanin, thus decreasing the incidence of hypopigmentation. The high repetition rate (10 Hz) permits faster treatment than the QSRL.

A number of techniques are available for modifying the wavelength of light obtained from YAG lasers, thus permitting the clinician a degree of flexibility with one laser. The simplest of these is ‘frequency doubling’ or ‘harmonic generation’ where high-intensity photons propagating through a non-linear, asymmetric crystal generate laser light at twice the input frequency (8) by placing a KTP (potassium-titanyl-phosphate) crystal inside the laser cavity itself and focusing the beam into the crystal. Since the frequency of light is inversely proportional to wavelength, the result is light emitted from the crystal with twice the frequency or half the wavelength of the incident light; invisible near-infra-red 1064 nm wavelength light passed through the KTP crystal produces green visible light at a wavelength of 532 nm which achieves good results in the removal of red tattoo pigment—a colour that is difficult to treat with the QSRL or the fundamental 1064 nm wavelength of the QSNd-YAG laser. Laser energy is delivered to the tissue by a flexible articulated arm. The distal end of the fibre is typically coupled to a handpiece for focusing.

The QSAlex laser (Table 1) is a solid-state laser containing a chrysoberyl crystal of aluminum tetraoxide ($BeO{:}Al_2O_3$) doped with Cr ions. The crystal is placed within the laser cavity where powerful flashlamps excite the Cr ions to produce red photons with 100 ns pulse durations at a wavelength of 755 nm; this wavelength is between those of the QSRL and the QSNd-YAG lasers. Theoretically, effects in human skin of the QSAlex laser should be similar to those of the QSRL with the added advantages of deeper penetration and less melanin absorption. The QSAlex laser beam is delivered to the skin through a flexible fibre-optic cable. Intensity is controlled by multiple internal reflections in the cable, resulting in a homogeneous beam with less variation from pulse to pulse. The QSAlex laser is operated at a repetition rate of 1 Hz with a 3 mm spot diameter.

## PATIENT CONSULTATION

Regardless of whether the QSRL, QSNd-YAG or QSAlex laser is used, at the time of the consultation the physician should inform the patient of the following so that there are no subsequent misunderstandings: (1) no guarantee for complete removal can ever be given due to variability in the depth of the tattoo as well as the chemical make-up of the pigment(s); (2) multiple treatment sessions will be required, as each successive treatment allows continued removal of remaining pigment in a ‘layered’ fashion; and (3) laser treatments will be spaced at 1–2-month intervals to allow the skin to heal completely.

## TREATMENT

Treated areas are overlapped by 10–15% of the beam diameter by moving the laser handpiece across the tattoo. Most patients are treated without anaesthesia. The laser pulse is generally described as being tolerable mild–moderate pain or discomfort, not unlike a 'rubber band' being snapped against the skin. A few laser pulses may be given to assess the patient's tolerance to treatment. If anaesthesia is desired, it can be administered locally by injections of 1–2% lignocaine with adrenaline (unless in a site where adrenaline is contraindicated), or topically with EMLA® cream applied under occlusion for 90 min.

Immediately after Q-switched laser exposure, an elevated white-ash discolouration is seen which is more marked in the tattooed areas than in the adjacent normal skin. It is thought to be the result of rapid, localizing heat-formed steam or gas which may occur around pigment particles. The opaque white appearance, oedema and hyperaemia of the adjacent normal skin usually resolve within 24 h. Subsequently, a crust appears over the entire tattoo which sloughs at 3–10 days post-treatment. Occasionally, tattoo pigment is seen within this crust. Postoperative wound care consists of topically applied antibiotic ointment and a non-occlusive dressing. Fading of the tattoo will be noted over the next 6–8 weeks. Re-treatments are usually performed at 4–8-week intervals. Re-treatment energy densities can be held constant, increased or decreased depending on clinical results. The great majority of patients require multiple treatments of the same area to obtain optimal fading.

Multiple studies have been published documenting the ability of Q-switched lasers to produce highly selective removal of tattoo pigment with minimal changes in skin texture or pigmentation (Table 2).

## Q-SWITCHED LASER TREATMENT OF TATTOOS

Goldman et al first proposed using ruby lasers for the clinical management of patients with tattoos in the early 1960s. In the first studies using the 1 $\mu$s ('long pulsed') ruby laser, a broad, deep zone of non-specific necrosis was produced in the skin which provided less than satisfactory results (9). Later in the same decade, several other investigators introduced the QSRL for tattoo pigment removal (10, 11). However, the expense and user experience required for operation of these early QSRL systems limited their accessibility, and thus this modality saw only limited use over the next decade.

The ruby laser was 're-discovered' by Reid et al (12, 13) in Scotland where clinical studies demonstrated that the QSRL effectively removed both amateur and professional blue-black tattoos without subsequent cutaneous textural change or scarring. Amateur tattoos cleared after an average of four to six treatments, whereas professional tattoos required one to three more treatment sessions. The first large clinical trial in the United States by Taylor et al (14) on 35 amateur and 22 professional blue-black tattoos produced similar results utilizing a 40 ns pulse width QSRL and energy densities of 1.5–8.0 J cm$^{-2}$ repeated at a mean interval of 3 weeks. Substantial fading or total clearing occurred in 78% of amateur and 23% of professional tattoos. Amateur tattoos cleared after four to six treatments, while professional tattoos faded significantly with six to eight treatments. An example of a patient treated with the QSRL taken from the archives of the Beckman Laser Institute and Medical Clinic appears in Fig. 1.

Further studies (15) demonstrated even better results using the newer 28 ns QSRL. Amateur tattoos were treated successfully. Professional tattoos required more treatments for good results (70% of tattoos were at least 75% cleared after an average of five treatments). Green pigmented tattoos responded variably but did fade. In summary, the QSRL was found to be highly effective for amateur tattoos, moderately effective for black professional tattoos, and less effective for brightly coloured professional tattoos.

Prior to treatment, tattoo pigment is found within membrane-bound intracellular granules in fibroblasts, macrophages and, rarely, mast cells (16). After QSRL treatment, the large deposits of pigment are broken into smaller particles. A brief neutrophilic response follows, and by Day 11, all the altered pigment particles are re-packaged into the same types of cells which are then removed by phagocytosis. The mechanism of fading and

*Table 2.* Summary of published results of tattoo removal with Q-switched laser systems

| Reference | No. of tattoos (amateur, professional) | Tattoo colour(s) | Laser | Patient response |
|---|---|---|---|---|
| 12, 13 | 416 | Blue-black | QSRL | Four to six treatments: amateur tattoo ‘clearing’ |
| | (341, 75) | | | Six to seven treatments: professional tattoo ‘clearing’ |
| 14 | 57 | Blue-black | QSRL | Four to six treatments: 78% of amateur tattoo ‘cleared’ |
| | (35, 22) | | | Six to eight treatments: 23% of professional tattoo ‘cleared’ |
| 15 | 28 | Blue, black, green | QSRL | Five treatments: 70% of tattoos cleared greater than 75% |
| 18 | 39 | Blue-black | QSNd-YAG | One treatment: 25–50% of ink removed |
| | (14, 25) | | | Four treatments: 77% of tattoos cleared greater than 75% |
| | | | | 28% of tattoos cleared greater than 95% |
| | | Multicoloured | | Four treatments: tattoos cleared less than 25% |
| 19 | 23 | Red | 532 nm QSNd-YAG | Three treatments: 75% of tattoos ‘faded completely’ |
| 21 | 23 | Blue-black | QSAlex | Average of 8.9 treatments: 87% of tattoos ‘cleared greater’ than 95% |
| | (8, 15) | | | Average of 7.8 treatments: 100% of amateur tattoos faded greater than 95% |
| | | | | Average of 9.7 treatments: 80% of professional tattoos faded greater than 95% |
| 22 | 42 | Blue-black, green | QSAlex | Average of 4.6 treatments: amateur tattoos ‘total clearance’ |
| | (18, 24) | | | Average of 8.5 treatments: professional tattoos ‘total clearance’ |
| 23 | 7 | Green, red, purple, yellow, orange | QSAlex | Average of 9.0 treatments: green ink completely removed |
| | | | | Average of 9.7 treatments: red ink completely removed |
| | | | | Average of 10.0 treatments: purple ink completely removed |
| | | | | Yellow and orange inks unaffected by laser |

QSRL, Q-switched ruby laser; QSNd-YAG, Q-switched Nd-YAG laser; QSAlez, Q-switched alexandrite laser.

*Fig. 1.* Forty-seven-year-old male with professional tattoo on right arm (a) prior to treatment, and (b) after six Q-switched ruby laser treatments.

removal of ink is unknown, and is postulated to be brought about by several mechanisms. First, during QSRL exposure, pigment absorbs the light energy and converts it rapidly to heat, causing a chemical alteration in the pigment granule structure sufficient to alter the optical properties of the tattoo and make it less apparent. However, post-treatment histologic studies still demonstrate considerable residual pigment in those tattoos which have been totally cleared clinically. Second, re-phagocytosis of the altered pigment particles reduces or eliminates the unwanted tattoo pigment substantially. Third, external elimination occurs as the crust is sloughed.

Significant absorption by melanin does occur at the 694 nm QSRL wavelength, and thus blistering and transient pigmentary changes occur with some frequency. Up to 50% of treated patients show some changes in the normal skin pigmentation, most commonly hypopigmentation and less commonly hyperpigmentation, which may last for several months. These changes are usually temporary and resolve over 6–12 months, but may be permanent in up to 10% of patients (14–16). Scarring is uncommon (<5% of patients) and occurs more commonly in professional than in amateur tattoos (14–16).

DeCoste and Anderson (17) showed the QSNd-YAG laser (1064 nm) with fluences of 6 J cm$^{-2}$ to be equally as effective as the QSRL in removing black tattoo ink but with less blistering and pain, fewer textural changes and no hypopigmentation. Subsequently, Kilmer et al (18) undertook a prospective, blinded, controlled, dose-response study to evaluate the ability of the QSNd-YAG laser (1064 nm, 10 ns, 5 Hz) to remove tattoos in 25 patients with 39 blue-black or multicoloured tattoos (14 previously untreated; 25 resistant to the long pulse duration, approximately 40 ns, experimental QSRL) using higher fluences. Each tattoo was marked into four quadrants and treated with 6, 8, 10 or 12 J cm$^{-2}$, one fluence per quadrant. After one treatment, 25–50% of the black ink was removed in all cases, including those tattoos treated previously with the QSRL. An excellent response (greater than 75% ink removal) was seen in 77% of the black tattoos, and more than 95% of the ink was removed in 11 (28%) of 39 tattoos at 10 or 12 J cm$^{-2}$ after four treatment sessions. Of the previously untreated tattoos, 11 of 14 were

*Fig. 2.* Sixty-year-old male with professional tattoo on left arm (a) prior to treatment, and (b) after eight Q-switched Nd-YAG laser treatments.

more than 75% clear, and four of those were more than 95% clear at the end of the study (four treatment sessions). The QSRL-resistant tattoos had a similar response (14 of 25 were greater than 75% clear, with six of those greater than 95% clear). Efficacy of tattoo removal was probably related to the longer wavelength, which allowed greater dermal penetration, less interference by surrounding melanin and excellent absorption by black tattoo ink. Multicoloured tattoos did not respond as well. Green, yellow, white and red inks were much more resistant to QSNd-YAG laser treatment, and cleared less than 25%, even after four treatment sessions, with more fading noted at the higher fluences. However, the frequency-doubled QSNd-YAG at a wavelength of 532 nm was the treatment of choice for red tattoo pigment which faded completely in 75% of patients with three treatments (19). An example of a patient treated with the QSNd-YAG taken from the archives of the Beckman Laser Institute and Medical Clinic appears in Fig. 2.

The QSNd-YAG laser causes more tissue and blood 'splatter' than other laser modalities. Immediately after treatment, the area turns grey-white and a wheal-and-flare reaction quickly follows. This is frequently accompanied by pinpoint bleeding, especially at higher doses. These responses were similar to those seen after QSRL exposure, although bleeding was more frequent, especially at the higher doses. Skin biopsied (18) following QSNd-YAG laser treatment showed not only identifiable tattoo ink in the dermis, but also altered morphology. The ink was present in cells predominantly located in perivascular regions. Superficial and mid dermal tattoo ink was markedly less coloured and the particles were smaller than in non-irradiated controls. Tattoo ink located greater than 1.5 mm from the surface was darker and the particles were larger than the more superficial ink particles. There was minimal or no fibrosis in the superficial dermis, and the hair and sweat glands appeared normal.

Side-effects of the QSNd-YAG laser at 1064 nm include textural changes (more frequently than with the QSRL) (19). Thus far, hypo- and depigmentation have not been noted with the 1064 nm wavelength; however, this could become a problem at higher fluences. Anderson et al (20) have shown that this wavelength was absorbed by melanin, and caused depigmentation at higher fluences in animals. The QSNd-YAG laser first harmonic green light at 532 nm is well absorbed by melanin, commonly leading to hypopigmentation. Erythema may persist for 4–6 weeks after treatment, particularly when higher doses are used. Post-inflammatory hyperpigmentation may also be a transient problem, particularly in patients with darker skin types.

Fitzpatrick et al (21) evaluated the ability of the QSAlex laser (755 nm, 100 ns) to remove tattoos in 15 patients with professional tattoos, and eight patients with amateur black and blue-black tattoos. There was a gradual and progressive fading of tattoo pigment as a result of treatment. Twenty patients (80%) cleared greater than 95%, averaging 8.9 treatment sessions. When the response of amateur vs professional tattoos was evaluated, the percentage of amateur tattoos reaching greater than 95% fading was 100%, while the percentage of professional tattoos reaching such fading was slightly less (80%). In human skin, the QSAlex laser produced an immediate grey-whitening of the skin followed by erythema and oedema. Histologic evaluation of tattoos at various stages of treatment revealed fragmentation of tattoo pigment granules, followed by macrophage engulfment and gradual clearing from the dermis. Alster (22) reported similar results in not only black and blue-black amateur and professional tattoos, but also in such tattoos containing green pigment, with no adverse effects. In both studies (21, 22), fluences utilized with the QSAlex laser ranged from 4 to 8 J $\mathrm{cm}^{-2}$, and the number of treatments required for significant clearing varied from two to 13, with amateur tattoos requiring a smaller average number of treatments. Transient hypopigmentation and textural changes occurred in approximately 50–80% and 12% of patients, respectively. Scarring as a direct consequence of laser interaction was not encountered in either study. In studies on multi-coloured tattoos, Stafford et al (23) reported excellent fading of green, red and purple pigments after QSAlex laser (760 nm, 50–100 ns) treatment. The only colours which have thus far been found to be consistently resistant to QSAlex treatment are yellow and orange.

A significant advantage of the QSAlex laser is decreased tissue 'splatter' during exposure, which may be the result of the longer pulse duration (100 ns compared to the QSNd-YAG 5–20 ns). Inasmuch as investigators have demonstrated the presence of viable viral particles in the plume given off by laser treatments, traumatic rupture of the skin surface has become of greater clinical significance, as hepatitis and human immunodeficiency viruses become more prevalent in some populations.

Multiple comparative studies have been performed assessing the efficacy of Q-switched laser treatment of tattoos. Zelickson et al (24) examined the responses of the QSRL (694 nm), QSNd-YAG (532 and 1064 nm) and QSAlex lasers (755 nm) in which 14 commonly used tattoo pigments were injected into guinea pig skin, and then the amount of fading produced by each system was compared. Evaluation showed that red brown, dark brown and orange pigments responded best to the QSNd-YAG laser (1064 nm). The QSAlex laser was most effective for removing blue and green pigments. For removing purple and violet pigments, best results were seen using the QSRL. The QSNd-YAG laser (532 nm) removed red pigment most effectively. Black pigment faded equally with the QSNd-YAG (both 1064 and 532 nm) and QSAlex lasers. Although no scarring was observed in the animals, histological and ultrastructural examination showed epidermal and dermal damage to be most evident after treatment with the QSNd-YAG laser, 532 nm producing greater damage than 1064 nm.

Levine and Geronemus (25) compared the QSRL (694 nm, 28 ns pulse duration, 8–10 J $\mathrm{cm}^{-2}$) with the QSNd-YAG laser (1064 nm, 5–10 ns pulse duration, 10–14 J $\mathrm{cm}^{-2}$) by treating one-half of each of 48 amateur and professional tattoos (39 professional, nine amateur) with each laser. The QSRL proved to be superior in fading black dye in both amateur and professional tattoos, and removing green pigment. Differences in tattoo removal between the two lasers were not clinically significant in the fading or removal of other colours. Hypopigmentation was found more frequently with the QSRL, especially in darker-skinned patients. Textural changes were more common following treatment with the QSNd-YAG laser; one patient treated with this laser developed a hypertrophic scar. Lastly, the QSNd-YAG laser 532 nm wavelength was superior to the fundamental 1064 nm and QSRL in the removal of red ink;

all tattoos containing red ink were removed completely in one to three treatment sessions.

McMeekin (26) compared the QSRL (694 nm, 25 ns, 6 J cm$^{-2}$) to the QSAlex laser (755 nm, 100 ns, 6 J cm$^{-2}$) in the treatment of 10 black amateur tattoos, and found that the QSRL was more effective in clearing all tattoos. Kaufman et al (27) compared the QSNd-YAG laser (1064 nm) to the QSAlex laser in the treatment of 50 tattoos, and saw better initial as well as long-term clearing with the former.

Two noteworthy complications have been observed after Q-switched laser treatment of cosmetic tattoos. After exposure, red or flesh-toned pigment used to mimic eyebrow, eye or lip liner and facial camouflage have turned black, brown, blue or green. Irreversible ink darkening can be an insidious complication because immediate whitening of the skin temporarily obscures the subsequently impressive colour change. Of six reported cases, two required surgical excision because further laser treatment was unsuccessful, while four were improved by additional laser sessions (22, 28). The mechanism of this change is unclear but it has been hypothesized that it may involve the reduction of ferric oxide ($Fe_2O_3$) pigment to ferrous oxide (FeO) (28). It is not currently possible to predict which inks will darken or, for that matter, which ones will respond to further treatment. Use of a small test area is always indicated prior to treating the entire tattoo to avoid this complication.

After treatment with Q-switched lasers, the intracellular pigment within fibroblasts and macrophages becomes extracellular and fragmented. This re-emergence of tattoo pigment in the skin may act as an antigen. Cutaneous allergic reactions to pigments found in cadmium-, chromium-, cobalt- or mercury-containing tattoo inks are not infrequent and are probably related to a cell-mediated (delayed) hypersensitivity reaction. Prophylactic administration of prednisone and hydroxyzine can prevent the re-occurrence of the allergic reaction in subsequent treatments, and should be considered in similar situations (29).

Traumatic tattooing results from the accidental deposition of foreign pigmented matter into the skin associated with abrasive or explosive trauma, with the former being a more common occurrence. Abrasive traumatic tattoos result from damage to the skin by friction or scraping that forcibly removes the upper skin layers with concurrent direct pressurized impregnation of pigmented particles. Explosive traumatic tattoos result from the forceful impregnation of gunpowder granules commonly caused by accidents involving fireworks, firearms, homemade bombs or dynamite. Studies have documented that QSRL and QSAlex laser provide dramatic pigment removal from traumatic tattoos of either origin (30, 31) without the undesirable side-effects of scarring or permanent pigment changes that occur with the use of other treatment modalities.

## CONCLUSION

It is apparent that no single laser will treat all tattoos; multiple wavelengths are necessary to treat multicoloured tattoos. In the next few years, it may be possible to define tissue reflectance characteristics of tattoos on an individual patient basis before laser exposure, and then choose a wavelength for treatment that will maximize absorption and destruction of a particular pigment colour (32). Many basic aspects of Q-switched laser treatment, such as the dependence of pigment photodisruption on pulse duration and the fate of tattoo inks after treatment, remain to be explored and, hopefully, optimized. Furthermore, the possible role of plasma formation in tattoo removal needs to be elucidated.

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