

# Laser-Tissue Interaction in Tattoo Removal by Q-Switched Lasers

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## ABSTRACT

Q-switched (QS) lasers are widely considered the gold standard for tattoo removal, with excellent clinical results, impressive predictability, and a good safety profile. The generation of giant pulses by the method of Q-switching is responsible for the unique laser-tissue interaction that is seen in tattoo removal by QS lasers. The QS lasers work by impaction and dissolution of the tattoo pigments. Mechanical fragmentation of the tattoo pigments encased in intracellular lamellated organelles followed by their phagocytosis by macrophages is thought to be the major event in the clearance of pigments by QS lasers. A few novel techniques have been tried in recent times to hasten the clearance of tattoo pigments.

**KEYWORDS:** Laser-tissue interaction, Q-switched (QS) lasers, tattoo removal

## INTRODUCTION

Through the years, many methods of tattoo removal, such as dermabrasion, salabrasion, surgical excision, and freeze-burning the tattooed skin with liquid nitrogen have been explored.<sup>[1]</sup> The advent of lasers brought new options for tattoo removal. The initial argon and CO<sub>2</sub> lasers have been replaced by the Q-switched (QS) lasers, which have, in recent years, become the mainstay for tattoo removal due to their ability to efficiently remove tattoo pigments with minimal side effects.

### The tattoo pigment: Composition and natural history

Tattoo inks are composed of pigments that are suspended in a carrier solution. The tattoo pigments range from inorganic materials to azo dyes, with variable absorption spectra.<sup>[2,3]</sup> They are primarily metal salts but can also be an assortment of plastics and vegetable dyes [Table 1]. The pigment provides the color of the tattoo. The carrier may be a single substance or a mixture. The purpose of the carrier is to keep the pigment evenly distributed in a fluid matrix, to inhibit the growth of pathogens, to prevent clumping of the pigment, and to aid in

application to the skin. The most common ingredients in the carrier are ethyl alcohol, purified water, witch hazel, Listerine™, propylene glycol, and glycerol.

The natural history of an intradermally placed tattoo is still largely unknown. Initially, ink particles are found within large phagosomes in the cytoplasm of keratinocytes and phagocytic cells as well as fibroblasts, macrophages, and mast cells. The epidermis, the dermoepidermal junction, and the papillary dermis appear homogenized immediately after tattoo injection. The ink containing phagocytic cells in the dermis

Table 1: Commonly used tattoo pigments

| Tattoo color | Pigments used  |
|--------------|--|
| Black        | Carbon   |
|              | Iron oxide   |
| Blue         | Logwood (extract from <i>Haematoxylon campechianum</i> ) |
|              | Azure  |
|              | Cobalt blue  |
| Brown        | Ochre  |
|              | Manganese ammonium pyrophosphate                         |
| Violet       | Quinacridone   |
|              | Chromium oxide (Casalis green)                           |
| Green        | Malachite green  |
|              | Lead chromate  |
|              | Ferro-ferric cyanide                                     |
| Red          | Curcumin green   |
|              | Mercury sulfide (Cinnabar)                               |
|              | Cadmium selenide (Cadmium red)                           |
| Yellow       | Cadmium sulfide (Cadmium yellow)                         |
|              | Curcumin yellow  |
| White        | Ochre  |
|              | Titanium dioxide   |
|              | Zinc oxide   |

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concentrate along the dermoepidermal junction, beneath a layer of granulation tissue closely surrounded by the collagen. The reinstatement of an intact basement membrane prevents any further transepidermal loss of pigment and a layer of fibrosis subsequently replaces the granulation tissue.<sup>[4]</sup>

**The QS lasers**

Q-switching, or quality switching, of a laser is a mechanism used to control the light output by concentrating all the energy into intense bursts or series of pulses by modulating the intracavity losses, the so-called Q factor of the laser resonator.<sup>[5]</sup> The technique is mainly applied for the generation of nanosecond pulses of high energy and peak power with solid-state bulk lasers. Laser devices that incorporate Q-switching are able to achieve selective photothermolysis due to their high energy and short-pulse duration. This can be applied in the setting of removal of the tattoo pigment to arrive at the desired clinical results without much damage to the surrounding tissues, and with relatively faster and uncomplicated healing time.<sup>[6]</sup>

The three short-pulsed, high-intensity, and pigment-selective QS lasers widely used today for tattoo removal are the following:

- a. The Q-switched ruby laser (QSRL) – the QSRL emits light at a wavelength of 694 nm and has a pulse duration of 28-40 ns.
- b. The Q-switched alexandrite laser (QSAL) – the QSAL has a near infrared wavelength of 755 nm, pulse duration of 50-100 ns, spot size of 2-4 mm, and a repetition rate up to 10 Hz.
- c. The Q-switched neodymium-doped yttrium aluminum garnet (QS Nd:YAG) laser – the QS Nd:YAG laser emits infrared light at 1,064 nm and has a pulse duration of 5-10 ns, spot size of 1.5-8 mm, and a repetition rate up to 10 Hz. The frequency can be doubled and the wavelength can be halved (532 nm) by passing the laser beam through a potassium titanyl phosphate (KTP) crystal.<sup>[3]</sup>

The broad absorption spectrum of the tattoo pigments suggests that variedly colored tattoos require different QS lasers for their removal [Table 2]. Though QSRL and QSAL have been the earliest lasers used for tattoos, QS Nd:YAG laser (1,064 nm), due to its longer wavelength, higher fluence, and shorter pulse, has emerged as the prototype laser for black and dark blue/black tattoo pigments.

**Mechanism of tattoo removal by Q-switched lasers**

QS lasers emit short, high-intensity pulses that cause thermomechanical destruction via photoacoustic waves, leading to the fragmentation of tattoo pigments encased

**Table 2: Ideal QS laser for various tattoo pigments**

| Color     | QS Nd:YAG<br>532 nm | QSRL<br>694 nm | QSAL<br>755 nm | QS Nd:YAG<br>1,064 nm |
|-----------|---------------------|----------------|----------------|-----------------------|
| Black     | X                   | X              | Ideal          | Ideal                 |
| India ink | X                   | X              | Ideal          | X                     |
| Brown     | X                   | X              | X              | Used*                 |
| Blue      | X                   | X              | Ideal          | Ideal                 |
| Green     | X                   | Used*          | Ideal          | Used*                 |
| Orange    | Used*               | X              | X              | X                     |
| Red       | Ideal               | X              | X              | X                     |
| Purple    | X                   | Used*          | X              | X                     |

\*With variable results

in intracellular lamellated organelles. The subsequent phagocytosis of fragmented ink particles results in gradual fading and clearance of the tattoo pigments.

Anderson and Parrish, in their landmark papers on skin optics,<sup>[7-9]</sup> propounded the theory of selective photothermolysis. This theory postulates that light of a wavelength that is absorbed by a target chromophore will selectively damage or destroy that chromophore if the fluence is sufficiently high and the pulse duration is less than or equal to the thermal relaxation time (TRT) of that chromophore. It follows, therefore, that if the laser pulse duration is less than the TRT of the target chromophore, heat diffusion does not take place and the damage is selectively confined to the target without any collateral injury to the surrounding tissues.

QS lasers work on the principle of selective photothermolysis and also produce an additional photoacoustic effect, producing shock waves that cause explosion of the target.<sup>[8,10,11]</sup> Very high energy to the tune of 300 MW is delivered in a very short period of time (5-100 ns), which leads to rapid thermal expansion. This produces shock waves that rupture the targeted ink particles.<sup>[12,13]</sup> Phagocytosis of the pigment by macrophages is the primary method of elimination. The ruptured fragments are directed by tissue macrophages either to the lymphatic channels or to the regional lymph nodes. Some fragments may be transepidermally eliminated as the posttreatment crust is sloughed off.<sup>[5,14]</sup>

To be selective, the pulse duration of the laser should match the TRT of the target. The estimated TRT of the epidermis is 1-10 ms and the TRT of the tattoo ink particles is 0.1-10 ns, although some newer estimates are in the range 10-100 ps.<sup>[5]</sup> The size of the tattoo ink particles is about 10-100 nm and is generally placed at a depth of 1.1-2.9 mm. Laser-tissue interaction produces intercellular steam and vacuole formation within the target pigment that cause a scattering of visible light, leading to immediate whitening. An audible popping sound is heard during the laser procedure due to the photoacoustic effect.<sup>[15,16]</sup>

## Variables influencing effective removal of tattoo pigment

There are several variables that influence tattoo removal using the QS lasers. Smoking, the presence of colors other than black and red, a tattoo larger than 30 cm<sup>2</sup>, a tattoo located on the feet or on the legs, one that is older than 36 months, one with a high color density, treatment intervals of 8 weeks or less, and the development of darkening phenomenon are associated with reduced clinical response rates.<sup>[17]</sup> The Kirby-Desai Scale is a useful index to correlate with the number of treatment sessions required for satisfactory tattoo removal. It is based on six tattoo criteria - skin type, location, color, amount of ink, scarring, and layering.<sup>[18]</sup>

## Novel techniques for faster clearance of tattoo pigment

### The R20 technique

The treatment course for acceptable clearance of tattoo pigment is often prolonged and expensive as it involves multiple sittings at prolonged intervals and the results are often unpredictable, leading to patient dissatisfaction. In this backdrop, Kossida *et al.*<sup>[19]</sup> have evolved the R20 technique to shorten the treatment duration with multiple passes of QS laser, given about 20-min apart in a single laser session. They used a QSAL (5.5 J/cm<sup>2</sup>, 755 nm, 100-ns pulse duration, and 3-mm spot size). It is hypothesized that with a stronger interaction of laser energy with tattoo ink in the deep dermis, there is immediate whitening due to gas bubble formation, which apparently inhibits penetration of the laser light into the deeper dermis, thereby limiting optical penetration. However, as whitening fades, the dermal gas bubbles dissolve after about 20 min. Therefore, administration of subsequent pulse can penetrate further, with each laser pass treating successively the deeper layers of the dermis. This technique may be worthwhile, especially when the conventional QS Nd:YAG laser treatment of tattoo fails in effective tattoo removal. Moreover, this technique can be time-saving and economical too.<sup>[20]</sup> However, there is a strong chance that the optical properties of the tattoo pigment might be altered by the first laser pass and this may have an adverse bearing on the efficacy of the subsequent passes.<sup>[3]</sup>

### The R0 technique

The total treatment time of 60-80 min with the R20 method presents difficulties for both the patient and the physician. A novel method is now being propounded to cut short this lengthy treatment session without compromising on efficacy and safety. The immediate whitening reactions produced during laser tattoo removal are clinically reduced by the topical application of perfluorodecalin. The frosting subsides within a mean of 5 s. This, therefore, facilitates rapid multiple-pass

treatment of tattoos that may then be accomplished in less than 5 min.<sup>[21]</sup>

### Combination laser therapy

Transepidermal elimination of the ink pigment could be further increased by disrupting the dermoepidermal junction zone via fractional photothermolysis.<sup>[22]</sup> This method, however, may require high density and doses in clinical practice, which may lead to more side effects. Another recent approach to successful tattoo removal with lesser number of sittings involves the novel combination of ultrapulse CO<sub>2</sub> laser followed by QS Nd:YAG laser in the same sitting.<sup>[23]</sup>

## CONCLUSION

QS lasers, based on the principle of selective photothermolysis, provide for techniques of tattoo removal that achieve selective removal of each tattoo pigment with minimal risk of scarring and/or pigmentary alteration. Since many wavelengths are needed to treat multicolored tattoos, a single laser system cannot be used alone to remove all the available inks and its combinations. Several studies<sup>[24,25]</sup> have concluded that picosecond pulses are more efficient than nanosecond pulses at tattoo particle fragmentation. Current research is, therefore, focusing on newer picosecond lasers, which may be more successful than the QS lasers in effective and rapid clearance of the new vibrant tattoo inks.

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