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Will Sub-Nanosecond Lasers Replace Nanosecond Lasers for Tattoo Removal?

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SUMMARY

With their short nanosecond pulse durations, Q-switched lasers have revolutionized the treatment of tattoos [1-3]. Nevertheless, the mechanisms for clinically observed tattoo clearance are still not well understood. Two mechanisms have been proposed: a) a thermal effect where tattoo particles are heated to sufficiently high temperatures to cause chemical changes within the particles and the surrounding cells; and b) a mechanical fragmentation of the particles due to extremely fast changes in the particles' temperature [1-4]. Theoretically, both mechanisms should be more effective towards shorter pulse durations. It is for this reason that sub-nanosecond, 750-900 picoseconds (e.g., 0.75 - 0.9 nanoseconds) tattoo-removal lasers [5, 9], have recently attracted considerable interest. However, as measurements of the dependence of the ablation threshold fluence on pulse duration in a wide range of pulse durations (as short as 0.1 ps) have demonstrated, the pulse duration is of importance only when the irradiated tissue is basically transparent to the laser light [6]. For highly absorbing tissues, such as tattooed skin, the ablation threshold fluence was found to be completely independent of the laser pulse duration, even when pulse durations were shortened from the nanosecond to sub-picosecond (0.1 ps) range [6]. The question thus arises whether the shortening of laser pulses will have any significant effect on tattoo removal efficacy, especially since the pulse duration of the current "picosecond" devices are only slightly shorter than one nanosecond.

In this contribution, we report on the preliminary results of a study of the influence of laser pulse duration on tattoo removal.

When tattooed skin is treated with a laser pulse fluence above a certain treatment threshold, plasma formation takes place and gas bubbles form around the tattoo pigment [7, 8]. This transformation is observed clinically as a whitening or blanching of the treated skin, signifying that the tattoo pigment reacted with the treatment light.

We measured the dependence of the plasma formation fluence, as observed when skin whitening occurred, on the treatment laser pulse duration. A laboratory Nd:YAG laser set-up was used which was able to generate pulses of the following durations (Table 1):

Table 1

Nd:YAG laser pulse duration			
50 ns	7 ns	5 ns	2 ns

Laser fluences where skin whitening occurred were measured on tattooed pig and human skin. For both, pig and human tattooed skin, and for the above wide range of tested pulse durations, the plasma formation threshold changed only slightly, from 0.8 to 1.00 J/cm^2, even though the pulse duration varied by a factor of 25 (from 2 to 50 nanoseconds). It is highly unlikely that a shortening of the pulse duration by another factor of 2.5 (to obtain sub-nanosecond pulses) would result in any further significant change. In agreement with previous studies which have showed the threshold for plasma formation in highly absorbing tissues to be insensitive to pulse duration, our results indicate that reducing the pulse duration into the sub-nanosecond range will not contribute significantly to the thermal mechanism for tattoo removal.

Another mechanism which could possibly improve with sub-nanosecond (750-900 ps) pulses, is the fracturing of tattoo particles under increased mechanical stress. However, as has been shown by previously published studies, tattoo particle fragmentation does not occur even when 20-times shorter (e.g., 35 ps) pulses are used [4]. A conclusion by the study was [4] that temperature-induced changes, rather than particle fragmentation, are responsible for tattoo clearing.

It is also worth noting that picosecond pulses of a sufficiently high fluence are difficult to generate, and that consequently the picosecond lasers are capable of delivering fluences above plasma formation threshold only at small spot sizes. These small spot sizes result not only in procedures being slow, but also in

unacceptable scattering losses, so that tissue penetration and treatment efficacy are compromised [4]. For example, current sub-nanosecond lasers are capable of generating a maximum fluence of 6.4 J/cm^2 only at the 2 mm spot size, while at the 3 mm spot size the maximum fluence falls down to only 2.8 J/cm^2 [5]. This is to be compared with the top-of-the-line Q-switched Nd:YAG lasers with 5 ns pulse durations, which can generate fluences of 12.7 J/cm^2 at 3 mm, 8.2 J/cm^2 at 5 mm, 5.7 J/cm^2 at 6 mm, and 3.2 J/cm^2 at 8 mm [7].

Clinical experience has also not confirmed that sub-nanosecond lasers are effective independently of whether the laser wavelength is matched with the color of the pigment. In a recent study with a sub-nanosecond alexandrite laser [9], no clearance of a red colored tattoo was obtained after four treatment sessions.

Another challenge with picosecond lasers is the optical breakdown in the air above the treated skin that occurs more readily at shorter pulse durations [4]. This might limit the usefulness of picosecond lasers because plasma would consume energy intended for treating tattoo particles. The picosecond lasers are also more complex devices and might be more difficult to maintain and service.

In conclusion, the published literature and our preliminary results seem to indicate that current "picosecond" lasers are not expected to have a significantly better tattoo clearance effect in comparison with the "gold standard" Q-switched nanosecond tattoo lasers. Taking into account also the current technology limitations of picosecond lasers, it is our opinion that top-of-the-line Q-switched nanosecond lasers will remain the devices of choice for tattoo removal.

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