Laser tattoo removal: is there light at the end of the tunnel or is it just the light of an oncoming train?

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The market for tattoos continues to boom, despite the latent health hazards, which are not to be underestimated. At the same time, a survey in Germany, Austria and Switzerland showed that at least 5% of tattooed people polled were considering having their tattoos removed.[1] In Germany alone, this translates to an estimated 10 million people with tattoos and a half-million potential patients – or rather clients – for the laser market.

For decades, physicians applied quality-switched nanosecond laser devices to destroy the pigment particles inside the dermis and lighten the tattoo colour. This procedure offers a low rate of permanent side-effects, but the lightening of the colour often remains incomplete. Thus, it was with great enthusiasm and equally great expectations that the first commercially available picosecond-domain laser for tattoo removal was launched in 2012. This new generation of lasers was developed to increase the efficacy of treatment in comparison with quality-switched nanosecond lasers used so far. It was also intended to shorten the overall number of treatment sessions as well as minimize adverse effects. In the meantime, two other lasers of this kind are on the market as well. All three of them have since been the focus of extensive advertising, not only by the industry, but also among dermatologists and plastic surgeons at professional conferences as well as in (scientific) articles. However, to date, no randomized comparative clinical trials have been published to confirm the superiority of picosecond pulses to nanosecond pulses.

The cornerstone for this new laser technology was laid nearly 20 years ago. Herd *et al.* from Harvard Medical School did a side-by-side comparison of guinea pigs to show that the 795-nm titanium:sapphire laser (500 ps) was superior to the 752-nm alexandrite laser (50 ns) in removing black tattoos.[2] Around the same period, a proof-of-concept study demonstrated the superiority of the 1064-nm Nd:YAG laser with a pulse duration of 35 ps vs. a pulse duration of 10 ns in lightening black tattoos in humans; all other technical parameters remained constant.[3] Ten years later, these two pioneering studies gave rise to a series of corporate-sponsored noncontrolled case series which unanimously concluded that picosecond-domain lasers had a greater efficacy in removing tattoos than the prevailing nanosecond technologies.[4,5]

Before we yield to the euphoria about this new laser technology – which is indeed promising – we should first critically discuss several biophysical aspects.

To begin with, laser–tissue interaction is explained by the theory of selective photothermolysis, which states that the duration, energy and wavelength of a laser pulse should be adapted to the target. This theory was originally developed to understand the interaction between laser pulses and soft tissue targets (e.g. blood vessels) that undergo coagulation or vaporization. By contrast, tattoos are solid foreign bodies in skin, and they may react differently to laser pulses than soft tissue. Furthermore, the wavelength of laser light applied is carefully adjusted to the well-known absorption spectrum of endogenous targets like haemoglobin or water. In the case of tattoo pigments, the selection of the proper wavelength is already difficult for nanosecond pulses and seems to be even invalidated for picosecond pulses.

As an initial approach, Ho *et al.* used model calculations of homogenous graphite particles (as a surrogate for black tattoo pigments) to show that tattoo particles are broken down primarily photoacoustically; they stated that the optimal pulse length was approximately 10–100 ps.[6] However, this was an overly simplified model as could be seen in other studies that illustrated the wide spectrum of morphological varieties, especially among black tattoo particles (carbon black) in terms of their shape and size.[7] Based on these findings, it seems unlikely that tattoo particles follow the principles of linear thermodynamics (as proposed by the theory of selective photothermolysis). Indeed, the optical and thermodynamic properties of tattoo particles were shown not only to change due to the morphological differences described above, but also due to increasing irradiation temperature and power intensity during laser treatment. For instance, at very high power intensities (such as the ones generated in the picosecond domain), two or more photons could simultaneously be absorbed from molecules, which would open a new field in laser medicine.[8]

It is also noteworthy that pulse duration (as short as 0·1 ps) seems to be significant only when the irradiated tissue is more or less transparent to the laser light.[9] Subsequently, it is worth considering whether shortening laser pulses can have any significant effect on efficacious tattoo removal – not least because current picosecond-domain devices have a pulse duration of only slightly shorter than one nanosecond (i.e. 350–900 ps).

Interestingly, in another study that examined the influence of pulse duration on the fragmentation of pigment particles, Humphries *et al.* demonstrated that a larger spot diameter and greater fluence had more of an impact on lightening, whereas the pulse duration did not.[10]

Finally, the chemical structures and absorption properties of most commercially available colour pigments are not known. Tattoo pigments that appear to have the same colour can have varying absorption properties. Also, it is unknown whether and to what extent the fragmentation of tattoo particles might improve when using a wavelength that matches the maximal absorption of the pigment. Yellow pigments show almost no light absorption of 532-nm laser light. In cases where yellow tattoos react on picosecond pulses with 532 nm,[5] another process of laser–target interaction must occur, e.g. nonlinear light absorption. Interestingly, in another study with a picosecond-domain alexandrite laser, a tattoo with red pigment showed no clearance after four treatment sessions.[4] Therefore, the company's claim to provide an 'unmatched tattoo clearance across the full colour spectrum' has yet too be proven in further comparative trials.

Last but not least, the European Commission is currently drafting EU-wide legislation for tattoo ink ingredients. The number of pigments used in tattoos will possibly be reduced due to regulations on carcinogenic, mutagenic or toxic substances. This will probably also change the light-absorbing targets in the future. The issue as to which pigments will be banned is still under discussion.

Given the biophysical issues in this discussion, it comes as no surprise that publications to date have featured before-and-after pictures that do not fulfil the high promises made by the manufacturers. A review of all prospective clinical studies involving picosecond-domain laser devices (as indexed in MedLine) showed that a total of 18 photos have been published, and none of them document complete lightening of the tattoo, whereas in 10 out of 18 cases there were even adverse events such as scars, changes in texture or hypopigmentation.

The use of quality-switched nanosecond laser devices for tattoo lightening has a long and successful history in medicine; both its efficacy as well as its limitations have been confirmed in many published clinical studies. In contrast, the efficacy of picosecond-domain laser devices is currently documented only by a few small case series. What remains unclear is the essential question as to whether this treatment modality is superior to the previous standard treatment when neutral and objective criteria are applied. Randomized controlled trials (ideally in a side-by-side comparison) are thus desperately needed to learn more about the true merits of this new generation of lasers. At the same time, a lack of published evidence (as is the case with tattoo removal via picosecond laser) does not necessarily correspond to a lack of efficacy. The documented cases of therapeutic success mean that there cannot be any question about picosecond lasers' efficacy in tattoo removal (especially when targeting very small particles[3]), and in the long run they will probably establish their role in dermatological laser therapy. For example, the prospective studies published to date have shown clearance in 4–5 treatment sessions. In contrast, it has been well established that nanosecond technology takes 6–12 treatments to achieve clearance.

By no means whatsoever is it our intent to discourage an open and long-overdue discussion, but rather to stimulate one in a scholarly and nonvitriolic manner. Also, we want neither to discourage the full potential of this new laser technology nor to discount physicians' clinical experience of the devices' efficacy. Yet, a major problem is brewing with companies that are eager to promote new lasers before efficacy and safety have been properly determined.

Conflicts of interest

None declared.

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