9 Tattoo Removal

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Summary

The prevalence of tattoos continues to increase, with the rising popularity and shift in cultural attitudes regarding body art and self-expression. Concurrently, tattoo removal procedures have also seen an increase in demand, due to either regret or changes in personal or professional life events. Over the past few decades, laser procedures have become the gold standard for safe and effective tattoo removal. Quality switched, or Q-switched, nanosecond pulse duration lasers have long been considered state of the art; however, more recently, picosecond pulse duration lasers have become the new standard of care. Additionally, adjunctive treatment modalities, such as the perfluorodecalin-infused silicone patch, have been shown to aid in rapidly reducing laser-induced opaque whitening, thus allowing for an increased number of passes in rapid sequence without increasing the risk of adverse events. These advances hold promise for improved treatment experience and enhanced clinical outcomes in laser tattoo removal moving forward.

Keywords: tattoo removal, laser, Q-switched laser, nanosecond, picosecond, perfluorodecalin

9.1 Introduction

Tattoo removal procedures have shifted dramatically over the course of history. The first evidence of attempted tattoo removal was observed in Egyptian mummies dated back to 4,000 BC; the ancient Greeks used salt abrasion or a paste made from white garlic cloves mixed with Alexandrian cantharidin.[1] Tattoo removal later shifted to excisional and destructive procedures such as surgical excision, cryotherapy, dermabrasion, or thermal cautery.[2] However, while still utilized for small or otherwise difficult to treat tattoos, these surgical procedures have the potential to result in poor cosmetic outcomes and significant scarring.[2]

The idea of laser tattoo removal began in 1963 when Leon Goldman first showed that 0.5-millisecond pulses from a ruby (694 nm) laser effectively targeted pigmented structures of the skin.[3] Despite this initial success, laser tattoo removal was performed largely by nonselective, continuous wave source lasers such as the argon and CO_2 into the 1980s.[4] In 1983, Anderson and Parrish introduced the concept of selective photothermolysis that allowed for laser-based destruction of specific components of the skin, such as pigment or melanin, while leaving surrounding tissue intact.[5] This formed the basis of modern tattoo removal.

9.2 Modalities and Treatment Options

Modern tattoo removal techniques and devices are derived from the principle of selective photothermolysis.[5] Different chromophores found in the skin (such as melanin, ink particles, hemoglobin, and water) preferentially absorb different wavelengths of light. As long as a target chromophore has greater optical absorption at some wavelength than surrounding tissue, it can be targeted selectively by a laser. Subsequently, the energy delivered by the photons is converted to thermal energy and dissipated at a rate determined by thermal relaxation time, or the time taken for a chromophore to lose half of its heat via diffusion. Thermal relaxation time is proportional to the size of target chromophore. For example, tattoo particles may have a thermal relaxation time of few nanoseconds, whereas leg venules correspond to a thermal relaxation time on the order of 100 milliseconds.[6] A pulse duration that is shorter than a chromophore's thermal relaxation time will ideally limit heat damage to only the targeted chromophore, whereas a pulse duration that is longer than the thermal relaxation time may result in the transfer of heat energy to the surrounding skin and cause unintended damage.[7] On the basis of selective thermolysis, the development of nanosecond Q-switched lasers, specifically the ruby (694-nm) laser, alexandrite laser (755 nm), and neodymium:yttrium aluminum garnet (Nd:YAG) laser (1,064 or 532 nm [frequency doubled]), made the treatment of tattoos possible.[8]

Although nanosecond lasers can be effective in tattoo removal, success is often achieved only after numerous treatment sessions. This is especially the case where specific colors are more recalcitrant or show pigmentary changes following laser irradiation.[9,10] Therefore, attempts have been, and continue to be, made to improve the process. In 1998, greater efficiency in the clearance of black tattoos was observed with picosecond rather than nanosecond pulse durations.[11] Rather than relying solely on thermal energy to destroy the tattoo particles, it has since been shown that these picosecond duration lasers heat their targets within such a short period of time to cause thermal expansion and vibration. This effect ultimately leads to photomechanical stress and fracture of the tattoo particles.[8] These subsequent fragments are smaller than what is observed after destruction by nanosecond lasers, and therefore likely better removed by circulating macrophages. By relying less upon a photothermal effect to achieve effect, picosecond pulse duration lasers minimize the potential for collateral injury to surrounding tissues. Smaller studies have demonstrated improvement in removal of traditionally more difficult tattoo colors, namely blue, green, and yellow pigments.[12,13]

Although it took more than a decade for the picosecond pulse duration laser to translate from benchtop to bedside, numerous picosecond devices are now commercially available. Commonly utilized wavelengths in these picosecond devices include 532, 694, 755, and 1,064 nm, with a range of 375 to 750 picoseconds; however, some devices also allow for nanosecond pulses.

Beyond selective photothermolysis and photoacoustolysis, fractional photothermolysis with ablative and nonablative fractional lasers has been successfully utilized in tattoo removal.[14,15,16] With laser excitation, tattoo pigments such as white and brown, which generally contain titanium oxide or ferric oxide, can turn black through a reduction reaction.[17] As these resurfacing lasers primarily target water and not pigment contained within exogenous tattoo particles, they offer another option for removal for certain ink colors. The infrared wavelengths are absorbed by water to damage (nonablative) or remove (ablative) microscopic columns of skin, called microscopic treatment zones (MTZs).[14] The areas around the zones of injury are unaffected and create an environment favorable for rapid wound healing.[14] Therefore, fractional lasers remove tattoo pigment physically, as well as by creating microscopic channels through which the pigment can migrate upward. It is then eliminated transepidermally in the form of exfoliated necrotic debris within approximately 1 week of treatment.[14,15,16]

9.3 Indications

The motivations for tattoo removal vary from individual to individual and are often multifactorial and complex. Prominent reasons for removal include unwanted details (such as the name of a prior partner), outdated tattoos, or inappropriateness of the tattoo regarding employment. A study comparing the motivations for tattoo removal in 1996 with those in 2006 found an increase in the prevalence of women getting as well as removing tattoos, compared to their male counterparts.[18] Ultimately, the increase in female patients requesting tattoo removal was linked to an increase in negative societal connotations for women versus men with visible tattoos, particularly for women in the professional job market.[18]

9.4 Procedural Planning and Counseling

9.4.1 Preoperative Evaluation

Prior to laser tattoo removal, it is imperative for the clinician to take a thorough past medical, surgical, and allergy history. Specifically, does the patient report any known medical conditions, or is the patient currently or has recently taken medications that could affect wound healing; similarly, it is important to determine if there is a history of gold therapy, keloid, postinflammatory pigmentary alteration, or current or recent use of isotretinoin. If treating on or around the mouth, determine history of oral herpes simplex virus. In addition to medical and surgical history, the patient should be asked if they have experienced any adverse events to laser treatments previously, including known allergic reactions. Recent or planned sun exposure or application of artificial tanner must also be discussed, as these lasers will target pigment whether endogenous or exogenous, potentially increasing the risk of complications. Therefore, it is advised not to treat tanned skin, and to avoid and protect healing areas from the sun afterward.

It is also important to get a good history of the tattoo of concern. If determined to be an amateur tattoo, this may have different clinical and management implications and expectations than a professionally administered tattoo. The pigment deposition in an amateur tattoo tends to have a much wider distribution throughout the dermis. Pigment density is generally lower and less uniform than that of a professional tattoo. Decreased density and fewer ink components found in an amateur tattoo generally translates to fewer treatment sessions required for removal. One study found a mean difference of 4.5 versus 8.6 visits for the removal of amateur versus professional tattoos, respectively.[19] The age of the tattoo itself is an important factor in pretreatment evaluation. Older tattoos that have started to fade are easier to remove and require fewer treatments. In addition to the age and type of tattoo, the colors of the tattoo are important. Specifically, it is important to determine if "white" ink or other colors that may have incorporated white were used to yield the final color. This is because treatment of these colors with nanosecond and picosecond lasers can result in a graying or darkening of the tattoo, known as "paradoxical darkening." Therefore, the colors will dictate which wavelength, or even type of laser, or lasers are most appropriate for removal (▶ Table 9.1).

Table 9.1 Tattoo ink colors and optimal device

Color	Wavelength (nm)	Pulse duration
Black	694; 755; 1,064	nanosecond; picosecond
Blue	755, 785	picosecond
Green	755, 785	nanosecond; picosecond
Purple	755, 785	picosecond
Red	532	nanosecond; picosecond
Yellow	532	nanosecond; picosecond
Orange	532	nanosecond; picosecond

Fitzpatrick skin type of the patient is another factor to consider in tattoo removal. Epidermal melanin often acts as the primary competing chromophore in laser tattoo removal. Due to differences in melanosome size and distribution, patients of skin of color are at greater risk of pigmentary alterations such as hypopigmentation and hyperpigmentation; they are also at increased risk of hypertrophic scarring and keloid formation.[20,21] In patients with darker skin types, threshold responses will normally occur at lower fluences, and longer wavelength devices such as the 1,064-nm Nd:YAG laser should be used to minimize epidermal damage.[21] Use of a protective barrier, such as hydrogel pads or the perfluorodecalin (PFD) infused silicone patch, may provide additional epidermal protection, minimizing risks. Regardless of skin type, patients with recent skin damage due to sun exposure should be instructed to delay treatment.

The specific location of a tattoo also presents unique challenges when evaluating for laser removal. Tattoos that are located on the distal extremities are subject to less lymphatic drainage, which causes less pigment clearance after laser treatment and requires more treatments to achieve complete removal.[22] The area of skin containing the tattoo itself should also be closely inspected to make sure that there are no signs of any malignant or premalignant lesions that can be hidden by certain tattoo pigments.[23] Another significant, but often overlooked, aspect of treatment that should be discussed with the patient is that of realistic expectations regarding treatment course, possible posttreatment appearance/clearance, and cost and time of treatment. Successful tattoo removal requires multiple treatment sessions, and the cost of, and time commitment to, the process can become considerable.[24]

9.4.2 Treatment Selection

Ultimately, laser selection is largely based on the primary pigments contained within the tattoo of concern. Because of the ever-increasing complexity of the pigments used in modern tattoos, as well as the cultural trend of an increasing number of pigments in each individual piece, it may be necessary for the use of multiple wavelengths, and possibly multiple devices and approaches, for removal of an individual tattoo. This combination approach is the preferred treatment method of the authors, potentially utilizing a PFD patch with nanosecond, picosecond, ablative, and/or nonablative lasers over the course of complete tattoo removal.

Nanosecond Lasers

The Q-switched nanosecond pulse duration lasers regularly utilized in tattoo removal include the ruby, Nd:YAG with and without a potassium titanyl phosphate (KTP) crystal, and the alexandrite lasers.[24,25] The Q-switched ruby laser was one of the first lasers to be employed in tattoo removal and operates at the 694-nm wavelength.[25] This laser has been most successful in removal of black and, less so, blue tattoo pigments. This wavelength is less effective with removal of red or orange pigments from the skin due to the reflection, as opposed to absorption, of light from the ruby source.[25] The targeting of black pigments makes the Q-switched ruby laser ideal for the removal of amateur tattoos, which most commonly utilize India ink pigment.[25,26]

The Q-switched Nd:YAG laser emits light in the infrared range at 1,064 nm.[26,27] This laser is commonly modified by the addition of a KTP crystal, allowing for the doubling of the laser frequency, "frequency doubled," so the same laser can operate at the 532-nm wavelength.[26,27] At the 1,064-nm wavelength, the Q-switched Nd:YAG laser provides excellent removal of black and dark blue pigments. The 1,064-nm wavelength has a deeper penetration and lower absorption by melanin, making it a safer choice for patients of skin of color. When operating at the 532-nm wavelength, the Q-switched Nd:YAG laser provides effective removal of red, orange, and some yellow pigments. The ability to operate in two different wavelengths makes the Q-switched Nd:YAG laser a choice for a tattoo with multiple pigments.[26,27]

The Q-switched alexandrite laser is another laser that can remove blue and black pigments.[28] Its greatest utility, however, may be its ability to remove green pigments, which are often noticeably left behind, particularly after the use of a Q-switched Nd:YAG laser. The removal of green pigments is possible due to the Q-switched alexandrite laser's emission at the 755-nm wavelength.[19,29] Thus, this laser can act as an excellent complement to other Q-switched lasers.

The selection of nanosecond lasers should be based on the primary pigments contained in the tattoo that need to be removed, as well as the patient skin type. Due to the ever-increasing number and complexity of the pigments used in modern tattoos, it may be necessary to use multiple lasers with different wavelengths for complete removal.

Picosecond Lasers

Picosecond lasers became commercially available within the last decade and are now considered by many to be the first choice for laser tattoo removal (▶ Fig. 9.1). As previously mentioned, closer approximation of thermal relaxation times of smaller particles and photomechanical effects allow these lasers to minimize thermal damage to surrounding tissues. Specifically, diameters of most tattoo pigment particles are between 10 and 100 nm, corresponding to a thermal relaxation time shorter than 10 nanoseconds, falling into the "subnanosecond" or picosecond range.[30,31] Early picosecond pulse duration lasers generated these pulses via mode locking, a process involving an oscillator coupled to an amplifier.[30] Picosecond lasers presently in use employ passive Q-switching, thus

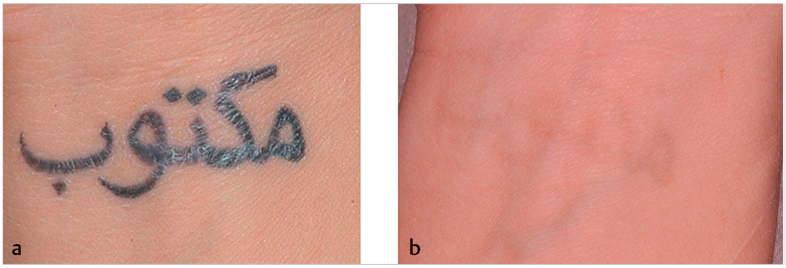

Fig. 9.1 Black tattoo treatment with 1,064-nm picosecond pulse duration laser. **(a)** Baseline. **(b)** Clearance after three sessions. (These images are provided courtesy of Dr. E. Victor Ross.)

reducing the need for bulky equipment while operating at multiple wavelengths and being more amenable to clinical practice.[30]

Laboratory studies on picosecond pulse duration lasers demonstrated superior clearance of tattoo pigment when compared to clearance by nanosecond pulse duration lasers.[11] Some pigments that have conventionally been more difficult to remove, such as blue, green, and yellow, have responded well to the picosecond laser.[12,13] As tattoo removal can be time-consuming and costly, the ability to potentially achieve clearance in fewer treatment sessions is of significant importance. Clinical trials, of which there are few, have only been done with small sample sizes. Therefore, although some studies have cited greater clearance with the picosecond laser than the nanosecond laser, any conclusions may lack definitive generalizability. A recent systematic review remarked on the scarcity of high-quality studies available.[31,32,33,34]

Picosecond laser treatment is associated with similar potential risks seen with nanosecond devices including but not limited to pain, dyspigmentation, erythema, edema, pinpoint bleeding, and scarring.[31,34] Studies assessing the safety of picosecond lasers reported comparable safety with regard to clinical scarring and histopathologic fibrosis.[12,31,32,33] Additionally, as with nanosecond lasers, picosecond lasers, when possible, should not be used on tattoos that may have iron oxide in the ink due to risk of paradoxical darkening, instead considering use of ablative lasers. There are occasions, however, where it may behoove the physician to intentionally induce this reaction and then continue to treat the tattoo, a technique that has been successfully demonstrated using a picosecond laser.[35]

The first commercially available picosecond laser was a 755-nm alexandrite laser with a pulse duration of 750 picoseconds. The Nd:YAG-based frequency-doubled 1,064-/532-nm picosecond laser was subsequently developed by two different companies, employing a two-stage system that effectively targets purple, red, yellow, and orange pigments in addition to black.[36] These systems incorporate three wavelengths, including 670 and 785 nm, as well as the option to treat at 2-nanosecond pulse duration. In recent years, more picosecond lasers have become available and operate at two or more wavelengths with multiple pulse durations, giving physicians the ability to target a spectrum of colors.

Ablative and Nonablative Lasers

Through fractional photothermolysis, ablative and nonablative fractionated treatment can offer an alternative method of tattoo removal for colors recalcitrant to selective photothermolysis.[14,15,16] Nonablative lasers utilize wavelengths in the near-infrared spectrum (1,320, 1,440, 1,540, 1,550, and 1,927 nm), whereas ablative lasers use energy in the mid-infrared spectrum (2,940 or 2,790 nm), or far-infrared spectrum (10,600 nm). Successful combination treatment with the carbon dioxide laser and Q-switched ruby laser has been reported and showed improved tattoo removal than with Q-switched ruby laser alone.[16] Similarly, erbium:yttrium aluminum garnet (Er:YAG) fractionated laser alone or in combination with a Q-switched Nd:YAG laser has been successful in patients with allergic tattoo reactions.[15]

An advantage of ablative and nonablative devices for tattoo removal is that the target chromophore is water, not tattoo pigments specifically, which is especially helpful for white, skin-colored, and multicolored tattoos, which as mentioned earlier carry a greater risk of paradoxical darkening. Whereas this can certainly be an advantage, treatment with these devices is not without risk, and multiple treatment sessions are often still necessary given the fractional pattern of injury. Specifically, the risk of excessive thermal damage and/or permanent scarring is greater with these resurfacing devices when compared to nanosecond and picosecond lasers, particularly for individuals of skin of color.

Perfluorodecalin Patch

Although laser tattoo removal is generally regarded as safe and effective, the lengthy treatment period usually required to achieve clearance is a major drawback. Traditional techniques have consisted of a single treatment session administered every 4 to 8 weeks.[37] A recent series demonstrated increased efficacy of removal when four passes are delivered over a single treatment session.[37] Specifically, upon completion of a laser treatment, the patient and treating physician would wait until the epidermal whitening reaction dissipated, at which time another treatment would be performed. The time for this to occur is approximately 20 minutes on average. This method, known as R20, may present practical limitations for both the patient and physician, as the time required for this dissipation of epidermal whitening and subsequent treatment would significantly extend a single office visit.

PFD is a stable, metabolically inert fluorocarbon liquid with several unique properties.[38,39] It has exceptional optical transparency from the ultraviolet (UV) to the far-infrared range.[40] Importantly, it has a well-known property of being able to dissolve gases, which has led to its use in first-generation artificial blood substitutes and liquid ventilation.[38,39] Of particular importance, laser-induced cavitation reaction generates gas bubbles that readily diffuse into the liquid PFD.[39] This critical property affords PFD the unique ability to immediately reduce the whitening reaction caused by this cavitation reaction.

The mechanism by which PFD clears the laser-induced cutaneous immediate whitening reactions in tattoo removal is mainly attributable to this gas transfer through tissues resulting in effective multiple-pass laser tattoo removal.[39] As this layer dissipates, optical clearing may play a role in the mechanism of action, allowing photons to penetrate more deeply with reduced optical scattering.

The safety and efficacy of a PFD-infused silicone patch has also been demonstrated in conjunction with both nanosecond and picosecond lasers.[41,42,43,44] A retrospective review was recently performed, including 45 consecutive patients of Fitzpatrick skin types I to V with black as well as multicolor (black, blue, green, red, and yellow) tattoos. All patients were treated with a 755-nm picosecond laser, with two patients receiving treatment with a 532-nm wavelength in the same treatment session. The mean number of passes per treatment session was 2.6 (range of 1–4 passes) and the mean number of treatment sessions necessary was 2.8 (range of 2–5 treatments). Notably, no dyspigmentation, scarring, textural changes, or unanticipated adverse events were reported.[44]

9.5 Technique

9.5.1 Procedural Preparation

Prior to laser treatment, the surface of the tattoo should be cleaned, and the laser should be calibrated. Providers should review patient's medical, surgical, allergy history; answer any patient questions or concerns; and take measurements and photographs. The informed consent should review risks of (such as pain, unsatisfactory cosmetic outcome, paradoxical darkening, scar, bleeding, and need for further treatments), benefits of, and alternatives to treatment. If necessary, providers should discuss options for anesthesia (topical, infiltrative, nerve block). Providers should also consider performing a test spot as an initial treatment and then bring back for follow-up if there are significant concerns for paradoxical darkening. This allows the physician to observe for the appropriate response and clinical outcome.

9.5.2 Tattoo Removal Procedure

The treatment area is anesthetized as discussed prior to treatment, via a topical ointment or locally injected lidocaine. Eye protection for the patient, physician, and support staff in the room is essential. Protective goggles are wavelength specific; it is important that all staff members involved are familiar with the appropriate safety equipment and protocols. In the case of cosmetic tattoos involving eyelids or eyebrows, utilization of intraocular shields is paramount.

When preferred and appropriate, the PFD is applied to the treatment area immediately followed by the patch. This process is then repeated anywhere from none to three additional passes during one session, depending on factors including but not limited to the anatomic location of the tattoo, Fitzpatrick skin type of the patient, as well as the current state or clearance of the tattoo. Laser treatment should be performed with the use of partially overlapping pulses of the chosen laser. The overlapping of pulses allows the clinician to avoid leaving certain portions of the tattoo untreated and prevent the aesthetically unappealing "honeycomb" appearance that can occur when the pulses are too far apart. The ideal response is tissue whitening in the treated area. An undesired response to the laser presents as epidermal disruption or bleeding that may indicate excessive fluence. In general, the physician should adjust the fluence of the laser accordingly when an undesired response occurs and also note that some pinpoint bleeding can be acceptable. Specifically, with a multiple-pass technique, it is important to take into account the cumulative energy and potential for injury, modifying parameters as necessary over the course of the treatment session.

9.6 Postoperative Management

After the laser procedure is completed, postoperative instructions should be reviewed with the patient, including but not limited to the application of an emollient and bandaging to the area for at least 1 week, or until healed, as well as appropriate sun protection. Expectations of skin whitening of the skin, which generally fades within 20 minutes, as well as the healing process should also be reviewed, including crusting, blistering, or pinpoint bleeding, and anticipatory guidelines should be provided. The treatment interval is determined by several factors, including skin type and anatomic location, but in general laser tattoo removal should not be performed sooner than 4 weeks. Some patients may experience an urticarial eruption following the laser treatment. Should this occur, patients are instructed to notify the physician and appropriate steps taken, including possible administration of an oral antihistamine and documentation of the subsequent reaction.

9.7 Potential Complications and Management

Complications of laser removal are often divided by time course into immediate and delayed reactions.[6] Many of the immediate reactions were those previously mentioned such as an urticarial reaction, pain, crusting, blistering, pinpoint hemorrhage, and paradoxical darkening. The most common long-term complications with laser treatment include hypopigmentation, hyperpigmentation, and scarring; patients should be appropriately counseled regarding sun protection and avoidance after treatment in order to minimize these complications (▶ Fig. 9.2). Rarely, the laser removal of red and yellow inks can cause the patient to develop an anaphylactic reaction or more commonly a systemic allergic reaction that is delayed weeks to months after treatment. This reaction is the result of the body's immune response to the specific chemicals and compounds that are released and carried away. Once identified, these reactions should be treated appropriately with topical, intralesional, or possibly oral corticosteroids and antihistamines.

Furthermore, in order to protect physicians and staff from the smoke emitted during tattoo removal, especially with ablative laser treatment, smoke evacuator, surgical mask, and/or other occlusive barriers should be used to minimize exposure to airborne contaminants.[45,46]

Fig. 9.2 Tattoo complication—dyspigmentation observed after treatment with a 50-nanosecond Q-switched alexandrite laser. (This image is provided courtesy of Dr. Brian Biesman.)

9.8 Pearls, Pitfalls, and Future Directions

The field of tattoo removal has been dynamic in recent years, especially with regard to shifting cultural attitudes toward tattoos, complex motives for seeking tattoo removal, and improving techniques and advancements in technology. Laser treatment continues to be the gold standard for safe and effective tattoo removal. Although the Q-switched nanometer laser is currently the most common treatment modality for these patients, the picosecond laser has rapidly come to be considered the new standard of care by many.

Selection of the appropriate patient, device, and parameters, in addition to following thorough pre-, intra-, and postoperative protocols, can minimize the risk of complications and maximize patient experience and results. Potential pitfalls such as unwanted hypo- or hyperpigmentation may occur with laser tattoo removal, especially in patients of skin of color. The selection of an appropriate laser, as well as counseling of patients regarding diligent sun protection before and after treatment, may also help minimize these complications. In addition, tattoo removal often requires multiple treatment sessions to achieve the desired cosmetic outcome; realistic and practical expectations should be discussed with the patient in each individual case. Given the potential discomfort, burden, cost, and time required, implementing a treatment strategy to allow for the largest amount of laser passes per session is becoming ever more essential. More recent advances, such as the PFD patch, can help rapidly reduce laser-induced opaque whitening to facilitate more passes in rapid sequence without additional adverse events. Incorporation of acoustic shock waves has recently been reported in conjunction with picosecond laser treatment for tattoo removal with promising potential.[47] These advances hold promise for improved patient experience and clinical outcomes in laser tattoo removal moving forward.

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