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REVIEW ARTICLE

DERMATOLOGIC THERAPY WILEY

Laser tattoo removal: Fundamental principles and practical approach

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Abstract

Tattoos have long become a part of human civilization. However, as the number of people who get tattoos increases, so is the number of people who wish to have their tattoos removed. Compared to other methods, laser-based devices are associated with the best efficacy and least side effects in tattoo removal. Lack of understanding of the fundamental principles of laser and managing its parameters may result in sub-optimal result and increased risk of side effects. Recognizing and mastering multiple factors including skin types, nature and color of tattoos, and proper selection of laser parameters such as wavelength, fluence, and pulse, are central in achieving an optimal tattoo removal outcome. This review provides a comprehensive overview on the fundamental principle of laser and practical approaches in tattoo removal.

KEYWORDS

laser, photoacoustic effect, tattoo removal, thermal relaxation time

1 | INTRODUCTION

The art of body tattooing has been recorded in human civilization back to thousands of years ago. The first historical evidence of tattoo is the finding of a well-preserved mummy, nicknamed Ötzi the iceman, with 57 tattoos in Ötzal alps, Italy in 1991. Besides its widely recognized function as an expression of art, tattoo also serves a number of other functions, such as a sign of belonging, healing from a disease, or even identification for criminals and slaves.[1]

For millennia, the making of tattoo was known as a time-consuming and excruciating process where each piercing was handmade using manual method. It was not until after the invention of electronic tattoo machine in the 1800s that tattoos became more widely available at a relatively more affordable cost.[1] A 2015 data estimated that 14% of all United States citizens had tattoo and among those of 25 to 40 years of age, at least 40% had a minimum of one tattoo.[2] However, the same data showed that 17% regretted their decision and 50% planned to remove their tattoos.[2] In 2011, The American Society of Dermatologic Surgery reported 100 000 tattoo removal procedures which was a 14 000 increase from the previous year. The reasons for tattoo removal varied, starting from the intention to create a new self-image in a new social environment to negative emotional perception of the old tattoo.[3]

The first attempt of tattoo removal was documented in 534 BC using salabrasion method, which involved inducing a mechanical or chemical injury on the tattoo followed by rubbing it with salt. As a result, the formation of scar tissue would surely be inevitable.[4,5] A more modern approach included methods such as dermabrasion, electrocauterization, cryosurgery, and chemical peeling have also been used to remove tattoo. However, these procedures were often unsatisfying and resulted in the formation of scar tissue as well as required long recovery time.[6] It was not until 1966 when Goldman et al[7] reported the first tattoo removal using laser for the first time that a much safer and more effective procedure was finally introduced. This was followed by a case-series report 3 years later using Quality-switched (QS) Ruby laser.[8]

From that time onwards, laser has become the cornerstone of tattoo removal. Traditionally, QS lasers are the first option in tattoo removal; however, lately picosecond (PS) lasers are starting to become more popular and are promoted to have a higher efficacy compared to QS lasers.[2] This review article aims to explore the fundamental principles of laser and its practical application in tattoo removal as well as the latest concepts in this field.

2 | LIGHT AND FUNDAMENTAL PRINCIPLE OF LASER

In the quantum level, light is defined as "packets" of energy, also known as photon, where each photon carries energy that is dependent on the wavelength of the photon.[9] An atom, on the other hand, is the smallest particle of an element and consists of a positively charged nucleus and one or more electron(s) that orbit(s) the nucleus (Figure 1A).[10] By definition, an atom will tend to stay at its lowest possible energy state (ground state) in order to remain stable.[11] In 1917, Albert Einstein described the "Quantum Theory of Radiation" that states when an atom absorbs energy, it will enter an "excited" state (Figure 1B) and upon returning to the ground state, it will release energy in the form of photon will be released (Figure 1C). In addition, when a photon collides with an excited atom, two photons with the same frequency will be produced and allows the atom to return to the ground state (Figure 2).[12] This phenomenon, termed "stimulated emission", lays the foundation for the development of laser-based devices.

Laser is an acronym for light amplification by stimulated emission of radiation. Devices that work on the principle of laser emit light with one wavelength that is parallel and minimally dispersed to form a monochromatic and focused light.[13] These properties are different from natural light and spontaneous light, such as that of a light bulb, which are products of photon emission at different time frame by atoms that are excited in different directions. Natural and visible light are usually composed of different wavelengths that results in an incoherent, divergent, and broadband nature.[12]

Most laser devices operate in visible wavelength which ranges from 390 nm (violet) to 700 nm (red) and near-infrared spectrum.[12] Despite the wide range and variety of laser devices, they are essentially made of four components:

1. Laser medium, may be in the form of solid, liquid, or gas
2. Resonator, also known as optical cavity, surrounds the laser medium and functions to amplify the resulting light. It consists of

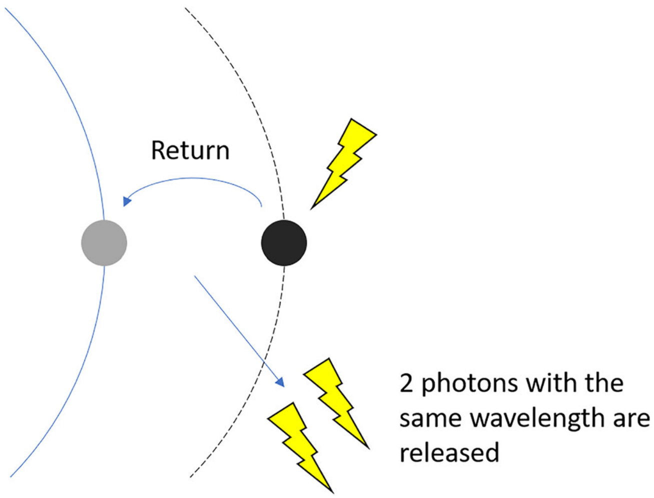

FIGURE 2 Stimulated emission. When a photon hits an excited atom, two photons with the same wavelength will be released as the electron returns to the ground state

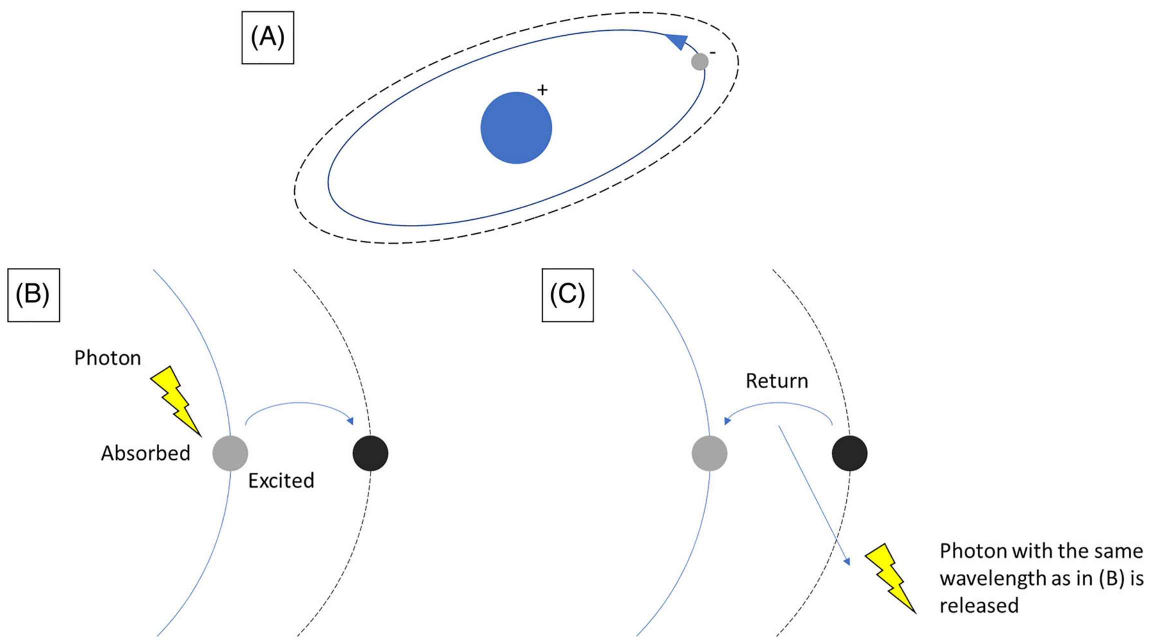

FIGURE 1 A, An atom at its resting position, composed of a positively charged nucleus and an electron orbiting around it. B, When the resting electron absorbs a photon, it will be excited into a higher orbit (shown by dashed black line). C, As an atom tends to stay at its lowest possible energy level to remain stable, the excited electron will return to its resting position and releases a photon with the same wavelength as it previously absorbed (spontaneous emission)

two mirrors, one opaque and one partially transmissible mirror, which are parallel to each other
3. Energy source, functions as a "pump" that excites atom and creates population inversion (explained below)
4. Delivery system, usually in the form of fiber optic or articulating arm with mirrored joints to deliver light to the target precisely

Laser devices are usually named according to the laser medium, for example gas lasers (argon, copper vapor, helium-neon, krypton, and carbon dioxide), liquid laser (pulsed dye laser), and solid laser (ruby, neodymium: yttrium-aluminum-garnet [Nd:YAG], alexandrite, erbium dan diode laser).[14]

Each laser medium produces a specific wavelength. This property is extremely important in tattoo removal as different chromophores have different optimal wavelength absorption (explain later in the next section). Some commonly used laser mediums and their corresponding produced wavelengths are shown in Table 1.

The energy source may take the form of direct electric current, optic stimulation by another laser, radiofrequency excitation, flash light, or chemical reaction.[14] The resultant energy will bring the electrons in the medium to an excited state which, upon returning to the ground state, release energy (photon) with a certain wavelength. When an excited electron collides with another photon with the same energy, a photon with the same wavelength will be released. As these photons are confined in the resonator, they will move in every direction and excite other atoms until the number of excited atoms exceeds the number of atoms in the ground state, a state called as "population inversion". Eventually, photons which travel parallel with the partially transmissible mirror will go out from the resonator as a laser beam which travels in a uniform direction.

The produced laser beam will have the characteristics of monochromatic, coherent, and collimated. Monochromatic means the beam only consists of one wavelength, which is extremely advantageous if the operator aims to target a chromophore (selective absorption). Coherent means that the wave travels in the same space and time; the peak and valley are synchronized across different waves, enabling the light to travel with losing significant intensity (minimal divergence). Collimated means that the wave travels parallelly in one axis, thus enabling it to travel long distance with only minimal distortion and dispersion. As a result, the energy can be condensed into a minimal light volume, therefore optimizing the amount of wave and energy delivered.[12,14]

TABLE 1 Laser mediums and their associated produced wavelength

Laser medium	Wavelength (nm)
Nd:YAG + KTP[a]	532
Ruby	694
Alexandrite	755
Nd:YAG	1064
CO_2	10 600

[a]Also called frequency-doubled Nd:YAG, the 532 nm wavelength is produced by passing the 1064 nm wavelength produced by Nd:YAG through potassium titanyl phosphate (KTP) which results in doubling of the frequency and consequently half the wavelength.

As laser is produced from the excitation of atoms, its temporal property is thus dependent on the temporal characteristics of the atomic excitation. In other words, when the energy supply is continuous, the output laser energy will also be continuous. Similarly, when the energy supply is limited on a certain time interval, also known as pulse excitation, the produced laser photon will also be pulsed. The duration of pulse may range from picoseconds to milliseconds and the produced energy will not be constant; instead, it will rise, reach its peak, and falls in a very brief period. In most cases, the output power of a pulsed laser may reach up to 100 times higher compared to a continuous laser.[12] This phenomenon can be understood using basic understanding of physics, where power is the product of energy per unit time. Thus, the shorter the time of energy expenditure (as in case of pulsed laser) is, the higher the power output will be.[15] Due to this reason, almost all procedures of tattoo removal are done using pulsed lasers.

3 | TATTOO CLASSIFICATION

A tattoo can be defined as the presence of pigment in the dermis, whether done on purpose or as a result of external trauma. Tattoos can be classified into five categories: professional, amateur, cosmetic, traumatic, and medical.[1]

3.1 | Professional tattoo

Professional tattoos are made by injecting pigment using a hollowed needle with constant vibration into the dermis which results in a uniform, high density ink deposition.[1,16] Tattoo ink is made of a mixture of organometallic dye to produce a variety of colors.[2,16] As the time goes by, the color will fade as a result of pigment migration to deep dermis and eventually to the lymph node through the lymph vessel. Thus, old tattoos will look faded and with unclear border.[16]

3.2 | Amateur tattoo

Amateur tattoos usually look less intense compared to professional tattoos and are injected using handheld needle or home machines and hence are easier to remove.[3] The needle used is not hollowed and only functions to deposit ink,[2] leading to less amount of deposited ink and color variations compared to professional tattoo.[16] Materials may vary, such as ash, charcoal, and Indian ink.[2]

3.3 | Cosmetic tattoo

Cosmetic tattoos, such as permanent eyeliner, eyebrow, and lipstick, are usually made with micropigmentation technique.[3] The color brown, black, flesh-tone, or red usually contain titanium dioxide and ferric dioxide which are challenging to remove as laser irradiation might induce oxidation that may instead further darken the skin (paradoxical hyperpigmentation).[16]

3.4 | Traumatic tattoo

Traumatic tattoos occur due to exogenous mechanical deposit of foreign objects such as metals, glass, dust, and carbon-containing particles following explosion or trauma that involves the surface of the railroad. This type of tattoo is especially difficult to remove if the materials are implanted in the deep dermis and/or contain explosive materials.[16]

3.5 | Medical tattoo

This type of tattoo is usually gray or blue-black in color and made due to medical purpose, such as radiation therapy, sign for medical device access, or corneal tattoo.[3,16] Similar to amateur tattoo, medical tattoos are usually made from Indian ink or carbon-based materials.[16]

4 | TATTOO REMOVAL

4.1 | Fundamental principle

The fundamental principle in tattoo removal using laser is the concept of selective photothermolysis. Since first introduced by Anderson and Parrish, it has become the basic rationale to target specific substances in the skin, such as melanin, pigment, water, and oxyhemoglobin, using laser while preserving the surrounding area.[16,17] These molecules are able to absorb laser of a certain wavelength and are called chromophores; different chromophores have different optimal wavelength absorption. When a chromophore absorbs photon of a certain wavelength, chemical reaction will occur and produce heat that propagate to the surrounding tissue. Thermal relaxation time (TRT) of a chromophore is defined as the required time to for a chromophore to lose 50% of the heat it experienced following laser exposure. Selective photothermolysis theory states that when a chromophore is heated with a duration of less than its TRT, chromophore destruction without damage to the surrounding environment will occur.[16] The bigger the size of chromophore, the longer is the TRT, and vice versa. Practically, the duration of TRT of a chromophore is equivalent to the square of the chromophore diameter in millimeter. For example, the TRT of a tattoo particle with a diameter of 0.1 μm (10^{-4} mm) equals to 10 ns (10^{-8} s).[9]

Besides thermal effect, photon absorption by chromophores also results in pressure force and is the basis for the inertial confinement time (ICT) concept which refers to the time required by pressure wave to traverse a target object. Mathematically, ICT is calculated by the formula d/v_a, where d is diameter of the target and v_a is the velocity of sound in the tissue (10^3 m/s). For example, the ICT for a tattoo particle with a diameter of 0.1 μm (10^{-7} m) is approximately 10^{-10} s or 100 ps. Similar to TRT, when a particle is hit by a certain amount of energy with duration of less than its ICT, mechanical stress capable of destroying the particle is generated (photoacoustic effect).[9] In case of tattoo, the deposited ink particle is located in the lysosome which resides in the fibroblast, macrophage, and dermal mast cells.[18] The destruction of lysosome leads to the release of the ink particle to the extracellular space which is then followed by phagocytosis. This process will transfer the pigment fragment into the lymphatic system and scavenging by dermal macrophages.[2,18]

4.2 | Laser parameter

Although there are numerous types and brands of laser-based devices on the market, every device essentially operates under the same rationale and can be operated to their full potential once the operator has a full comprehension of the parameters.

4.2.1 | Pulse width

As mentioned in the previous section, pulsed lasers have a much higher output power compared to continuous lasers.[15] Thus, almost all, if not all, cases of tattoo removal are done using pulsed laser. Pulse width is defined as the duration of which the laser is applied to the skin.[19] This parameter differentiates the Q-switched (QS) and picosecond (PS) lasers. In line with TRT concept and diameter of tattoo particle, a minimum of nanosecond pulse is required in order to achieve an optimal result.

4.2.2 | Fluence

Fluence or energy density is defined as energy per unit area (J/cm^2) and may be regarded as the “local dose” of a laser device.[9,20] Fluence needs to be adjusted such that the clinical endpoint in tattoo removal, which is the immediate whitening, can occur without inducing bleeding or blister formation. As a rule of thumb, high fluence is used in faded tattoos or when the amount of target chromophore is less while low fluence is used in tattoos with intense color or layered tattoos.[6]

4.2.3 | Spot size

Spot size defines the diameter of a laser beam in millimeter. When photons penetrate the dermis, they will be scattered by collagen fibers. If they are scattered outside of the laser area, the energy will be wasted.[19] With regard to this phenomenon, photons will tend to be scattered more when a small spot size is used, causing a decrease in laser penetration and an increase in the risk of epidermal injury (as the action of the energy will tend to be more superficially).[6,19] On the contrary, larger spot size results in a greater preservation of photons and thus increasing dermal penetration and minimizing epidermal injury.[6,19]

4.2.4 | Repetition rate

Repetition rate (RR) is the rate of pulse firing in 1 s; 1 Hz equals to one pulse being fired every second. A high RR is typically used in broad and flat lesions to reduce therapy duration while low RR is used in cases requiring high precision, such as when the lesions are small, discrete, or are located on uneven surface.[21]

4.3 | Preoperative considerations

Prior to conducting laser therapy, several factors need to be considered as they may predict the number of therapy and prognosis. Identifying whether the tattoo is made by professional or amateur artist is important due to the difference of ink composition, density, and depth. Professional tattoos tend to require more sessions compared to amateur tattoos. Old tattoos might need less sessions compared to newly made tattoo as some ink particles have been physiologically eliminated in the former. Tattoos with more than one color often require the use of more than one wavelength. Those of tan, brown, flesh-color, or white colors are commonly composed of ferrous oxide or titanium tioxide and pose a risk for paradoxical hyperpigmentation if not properly managed. History of allergy during the making of tattoo is also important as this allergy may recur during tattoo removal. Patients with darker skin type are prone to hypopigmentation following laser procedure.[16]

In order to predict the number of sessions needed in laser-based tattoo removal, Kirby et al[22] devised a scoring system known as the Kirby-Desai scale. Table 2 shows the aspects that are included in the Kirby-Desai scale, which are Fitzpatrick skin type, location, color, ink intensity, the presence of scar tissue and tissue damage, and the presence of layering tattoo.[2,22] The estimation of the number of sessions required to achieve a satisfactory outcome is the sum of all scores ±2.5 sessions.[2] Generally, a professional tattoo with requires 12 to 16 sessions, even up to 20 sessions. Amateur tattoo usually requires less therapy, around 4 to 8 sessions.[6] However, it has to be kept in mind that these numbers are only approximation and highly depend on various factors.

Whether isotretinoin consumption in the last 6 months is a risk for keloid development is still controversial. However, recent evidence suggested that history of isotretinoin administration did not increase the risk of postlaser keloid.[1] History of gold crystal administration, such as in cases of rheumatoid arthritis, has been shown to increase the risk of chyrisiasis,[1] which is gray-blue pigmentation resulting from the conversion of crystal gold to elemental gold.[23] Other contraindications include infection and/or dermatosis on the treated area, suspicion of malignant lesion, history of deep chemical peeling, dermabrasion, or radiation in the last 6 months, history of keloid, blood clotting abnormalities, and history of sunburn in the last 2 weeks.

4.4 | General approach

Prior to conducting laser therapy, especially in patients with dark skin, it is advisable to conduct test spot which can be evaluated after 4 to 6 weeks to assess the risk of hypopigmentation or hyperpigmentation as well as efficacy.[2] The desired response in both QS and PS laser is immediate whitening, which is the development of the color white or gray shortly after laser is shot. This phenomenon occurs as a result of lysosome cavitation, which is also accompanied by a popping sound.[18] Sometimes pinpoint bleeding may also occur.[2]

Topical or infiltration anesthesia is generally applied before procedure. Eye protection for everyone in the room, including for both operator and patient, using wavelength-specific goggles is mandatory. If the treated area is located in close proximity to the eyes, intraocular eye shield needs to be applied to the patient.[16]

It is recommended to initiate therapy from the lowest fluence that is effective to achieve immediate whitening. Fluence can be increased in latter sessions as the ink density decreases. When the fluence is increased, one has to anticipate and be aware of the development of pinpoint bleeding. It is a common and safe practice to do one pass with minimal overlap (<10%). Duration between sessions is approximately 1 month to ensure an optimal ink clearance and wound healing.[16]

TABLE 2 Kirby-Desai score

Point	Fitzpatrick skin type	Location	Tattoo color	Amount of ink	Scar tissue	Layered tattoo
0	–	–	–	–	None	Present
1	I	Head and neck	Black	Amateur	Minimal	–
2	II	Upper trunk	Mostly black with some red	Minimal	–	None
3	III	Lower trunk	Mostly black and red with combination of other colors	Moderate	Moderate	–
4	IV	Proximal extremities	Multiple	Significant	–	–
5	V	Distal extremities	–	–	Significant	–
6	VI	–	–	–	–	–

4.5 | Laser selection

The size of tattoo ink particle varies from 30 to 300 nm which corresponds to short TRT (<10 ns).[24] Thus, based on the selective photothermolysis concept, a laser pulse in the nanosecond range or shorter is required.[25] Consequently, QS lasers which work in nanosecond pulse is the most commonly used modality; PS lasers which work in picosecond range is a new contender for QS lasers.

As the optimum wavelength absorption of different chromophores varies, selecting the adequate laser wavelength is of paramount importance. Table 3 shows the optimal wavelength absorption for each tattoo color.

4.5.1 | Dark blue and black

Fitzpatrick skin type I to III

In this group, both QS and PS lasers with 694, 755, and 1064 nm wavelengths are effective.[2] However, it is important to ensure that the tattoo is not a traumatic tattoo resulting from combustible materials, such as gun powder, as this may trigger micro explosions and the formation of scar tissue.[16]

Fitzpatrick skin type IV to VI

In patients with darker skin types, long wavelengths are recommended due to a lower risk of epidermal injury compared to shorter wavelengths. Thus, QS or PS lasers with 1064 nm wavelength are more recommended in this population to those of shorter ones.[16]

Leuenberger et al[26] compared the effectiveness of QS Ruby, QS Nd:YAG, dan QS Alexandrite on 26 patients with blue-black tattoo and found that QS Ruby resulted in the most significant improvement. However, this was also followed by the highest incidence of hypopigmentation (38%) compared to Nd:YAG (0%) and Alexandrite (2%). The 1064 nm wavelength of Nd:YAG selectively targets pigment in the dermis with minimal effect on melanocytes and keratinocytes in the epidermis, making it as the ideal wavelength in patients with dark skin types.[1]

A large-scale trial on 404 Fitzpatrick skin type V and VI patients using QS Nd:YAG 1064 nm (380 patients) and QS Ruby (24 patients) reported 75% to 100% improvement on 92% patients after 3 to 6 weeks of therapy with an interval of 8 weeks. Mild hyperpigmentation persisting for 2 to 4 weeks was observed in 44% subjects and mild textural changes was found in two patients. No incidence of scar tissue or permanent pigmentary changes were observed.[27]

TABLE 3 Optimal wavelengths for different colors

Tattoo color	Optimal wavelength (nm)
Black	694, 755, 1064
Green	694, 755
Blue	694, 755, 1064
Red	532
Orange	532
Yellow	532
Purple	694, 755
Tan/nude/white	10 600

Note: 532 nm (Frequency-doubled Nd:YAG), 694 nm (Ruby), 755 nm (Alexandrite), 1064 nm (Nd:YAG), 10 600 nm (CO_2).

4.5.2 | Red

The optimal wavelength for red tattoo is 532 nm[2] which was shown to be more effective compared to QS Nd:YAG 1064 nm and QS Ruby 694 nm.[28,29] However, this wavelength is not recommended in patients with Fitzpatrick skin type IV to VI due to the high risk of dyspigmentation in subjects with dark skin. In addition, the color red often induces allergic reaction during tattoo making and this reaction may recur during tattoo removal.[2] In such occasion, the use of ablative CO2 and Er:YAG lasers are more advocated. If QS and PS lasers are to be used, it is advisable to administer systemic corticosteroid and antihistamine and conduct the procedure with extra caution.[2]

4.5.3 | Green

There are some views regarding the optimal wavelength for green tattoo removal. Some studies found that QS Ruby 694 nm resulted in the most significant improvement[2] whiles others recommended QS Alexandrite 755 nm.[16] As mentioned above, extra caution needs to be applied when using QS Ruby 694 nm due to the higher risk of transient and even permanent dyspigmentation caused by shorter wavelengths.[2] Both QS and PS Nd:YAG lasers are not effective in removing green tattoos.[30]

4.5.4 | Cosmetic or nude

The removal of cosmetic or nude tattoos is often challenging as they frequently contain red, brown, flesh-color, and white colors which contain ferric oxide and titration oxide. Both substances may induce paradoxical hyperpigmentation which may be due to the reduction of ferric oxide (Fe_2O_3) to ferrous oxide (FeO) and titanium dioxide (Ti^{4+} to Ti^{3+}); thus, test spot is highly recommended before treating the whole area.[2] Due to this risk, treating this type of tattoo with ablative lasers (CO_2 or Er:YAG) is preferred.[31]

When paradoxical hyperpigmentation has occurred, some studies have shown that multiple sessions of QS Nd:YAG 1064 nm laser treatment,[2] which may take up to 20 sessions,[32] and ablative lasers can be attempted.[33]

4.5.5 | Multiple colors

In cases of tattoos with multiple colors, the use more than one wavelength is often required. Usually, areas with black or dark colors are first treated using QS Nd:YAG 1064 nm before specifically targeting other areas with more specific wavelengths. However, it needs to be remembered that various colors of tattoos are often constituted of complex substances that may require trial and error approach.[1,2]

4.6 | Clinical application

After understanding the basic laser principles and parameters and rationale in choosing laser, an operator needs to know how to put these principles into practice. Depending on multiple factors, parameters need to be adjusted to achieve an optimal result and reduce the risk of side effects.

4.6.1 | Fitzpatrick skin types

Therapy on subjects with Fitzpatrick skin type IV to VI is usually initiated with large spot size (6-8 mm) and low fluence. On the other hand, therapy on patients with lighter skin color (type I to III) is usually initiated with small spot size (4-6 mm) and higher fluence. For example, black tattoos on a Fitzpatrick skin type V subject can be first treated using 8 mm spot size and 1.5 J/cm^2 fluence while the same tattoo on Fitzpatrick skin type II subject can be initiated with a 6 mm spot size and 2.5 J/cm^2 fluence.[6]

The reason why the fluence is decreased when the spot size is increased and vice versa lays on the fact that depth of light penetration decreases as the skin color gets darker.[34] As smaller spot size results in more scattering and hence a more superficial effect, it needs to be balanced with higher fluence in order to achieve the same depth. Thus, in patients with darker skin color, where depth of penetration is less compared to that in lighter skin color, a larger spot size is used to achieve a deeper penetration and a lower fluence is applied to achieve the same total energy output and effect. However, it needs to be remembered that despite the role of fluence and spot size, wavelength is the ultimate governor of penetration depth.[35]

4.6.2 | Ink color

Generally, it is advisable to initiate treatment with 1064 nm wavelength regardless of the color. A more specific wavelength can be used in subsequent sessions as the remaining colors have become more visible.[6]

4.6.3 | Ink intensity

Professional tattoos with dark color require larger spot size and lower fluence while amateur tattoos or tattoos that have been treated in several sessions with less intense colors require smaller spot size with higher fluence. For example, an intense black-colored tattoo can be first treated with 6 mm spot size and 1.5 J/cm^2 fluence while treatment of a black tattoo which has started to fade can be first treated with 4 mm spot size and 3.5 J/cm^2 fluence.[6]

4.6.4 | Layered tattoos

Layered tattoos generally have higher ink density; thus, in most occasions, treatment is first initiated with large spot size and low fluence to avoid overtreatment.[6]

4.6.5 | Size and location

Treatment of medium or large-sized tattoos can be initiated with high repetition (eg, 10 Hz) while in cases of small tattoos, especially those located on the face, lower repetition (eg, 2-5 Hz) can be used to achieve a higher precision.[6]

4.7 | Posttreatment therapy

Posttreatment pain and edema are commonly observed which can be overcome by cold compression using ice.[3] Sun avoidance, emollient application, and the use of bandage are recommended for a minimum 7 to 10 days after procedure.[2] Some suggest sun avoidance up to a few months after treatment.[1] Vesicles and crust formation during this period are possible findings and patients need to be well educated.[16] Subsequent session can be done after approximately 4 weeks.[1]

5 | RECENT DEVELOPMENT AND TECHNIQUE MODIFICATIONS

5.1 | Picosecond lasers

As mentioned above, PS lasers work in picosecond range. Due to this extremely short pulse duration, they are expected to have a more massive and destructive photomechanic effect compared to QS lasers and are the latest development of laser technology.[3] Most tattoo particles have a diameter of 100 nm with TRT <10 ns. Thus, theoretically, PS lasers are expected to be superior to QS lasers in tattoo clearance.[5]

Despite this theoretical difference, head-to-head comparative studies between QS and PS lasers are still limited. In terms of black and/or blue tattoos, three randomized, split-study, examiner-blinded trial involving 44 subjects, 18 subjects, and 16 subjects showed that PS lasers were superior to QS lasers.[36-38] The first study found that 33% of subjects treated with PS lasers obtained 75% or more improvement compared to 14% of subjects treated with QS lasers (P = .008).[36] The second study showed subjects treated with PS lasers experienced a more significant tattoo clearance compared to those treated with QS lasers as assessed by a 5-point scale assessment with a score of 3.8 and 2.7, respectively, where 0 denoted no improvement and 5 denoted total clearance.[37] The third study showed more than 70% improvement was evident in 11 patients treated with PS lasers compared to none of the areas treated using QS lasers.[38] On the contrary, two studies by Pinto et al and Zhang et al on 40 and 30 black tattoos, respectively, showed conflicting results, where in both studies no significant difference was observed between PS and QS lasers.[39,40] It should be remembered that, however, in the study by Pinto et al, the average fluence of the QS laser was more than twice of the PS laser.

In terms of multicolored tattoos, to date, comparative studies are still scarce. While a head-to-head study showed that PS lasers did not result in a more significant improvement compared to QS lasers,[36] a recent trial suggested that PS laser resulted in a superior clearance of red and green tattoos compared to QS laser.[37]

The most comprehensive systematic review to date concluded that, provided with equal parameters, PS lasers are more likely to result in a superior tattoo clearance outcome compared to QS lasers. In order to achieve similar results, QS lasers on average required far greater fluence than PS lasers and consequently higher risk of side effects. In addition, they recommended that PS lasers to be used as the gold standard for laser tattoo removal of any color with level of evidence of 1A.[41]

5.2 | Combination therapy

Tattoo treatment using a combination of pulsed Er:YAG or ultrapulsed CO_2 with QS Nd:YAG, also known as rapid tattoo removal technique (RTR), has been suggested to require less sessions compared to QS Nd:YAG laser monotherapy.[42] Besides that, a case-series on combination of QS with fractional lasers also showed improved tattoo clearance and reduced incidence of side effects compared to QS alone.[43] The ablation zone resulting from fractional laser was thought to increase QS laser penetration and dermal intercellular fluid clearance, thus resulting in increased effectiveness[44] and lower incidence of edema.[43]

5.3 | Multipass therapy

This approach, also known as the R20 method, was first coined by Kossida et al. In this technique, a total of four passes, each with 20 min interval after immediate whitening is no longer visible, is done. A study of 18 tattoos showed that after 3 months, tattoos treated with this method showed superior improvement compared to those treated with conventional therapy with no scar tissue development. Of all subjects, only one patient reported transient hypopigmentation that showed full resolution after 6 months.[45]

Reddy et al[46] modified this technique by applying perfluorodecalin solution to immediately eliminate immediate whitening; using this technique, the second and subsequent passes can be immediately done without having to wait for 20 min, a technique called as R0 method. This study also showed that R0 resulted in greater efficacy compared to conventional method.

6 | CONCLUSION

Laser therapy is the current tattoo treatment with the best efficacy. Mastering the fundamental laser principle and rationale behind the selection of various laser wavelengths and parameters is crucial in achieving an optimal tattoo removal. To date, QS lasers remain the most commonly used therapy with the best available evidence. Some newer approaches such as PS lasers, combination method, and multipass therapy are continuously developing with the goal of increasing tattoo clearance while minimizing the side effects.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTION

Ivan Kurniadi conducted the literature review, data synthesis, did the final editing, and approved the final manuscript. Farida Tabri supervised, critically reviewed, and approved the final manuscript. Asnawi Madjid supervised, critically reviewed, and approved the final manuscript. Anis Irawan Anwar critically reviewed and approved the final manuscript. Widya Widita critically reviewed and approved the final manuscript.

DATA AVAILABILITY STATEMENT

Data are freely available from the cited articles.

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