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Application of Picosecond Laser in Dermatology

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ABSTRACT
Background: Lasers are one of the most important treatment modalities in dermatology. Lasers interact with chromophores through several mechanisms that depend on fluence and pulse durations. Early lasers worked by photothermal interaction with pulse durations of 1 microsecond to 1 second. A picosecond laser is developed to confine photothermal effects and produce photomechanical effects and plasma induction. **Purpose:** To understand the mechanism of action and application of picosecond lasers for dermatological disorders. **Review:** Non-fractional picosecond lasers work by photomechanical interaction. Photomechanical interaction happens when pulse duration is less than inertial confinement time, causing fractures of chromophores with lower energy, or "cold ablation". Fractional picosecond lasers work by laser-induced optical breakdown (LIOB). In LIOB, accelerated seed electrons cause an electron avalanche that produce a collection of free electrons called plasma, which ablates tissues. LIOB in the skin is always followed by photodisruption. In LIOB, vacuoles and debris were eliminated transdermally and dermal collagen and elastin increased. Picosecond laser may be applied in disorders requiring destruction of chromophores and for collagen and elastin disorders. It is currently the first-line treatment for tattoo removal (Nevus of Ota and Acquired Bilateral Nevus of Ota-like macules, or ABNOM). It has good efficacy and safety for solar lentigines, freckles, and cafe-au-lait macules (CALM). It is an additional treatment for moderate to severe melasma and hypertrophic scars, in combination with other treatments. The fractional picosecond laser showed moderate improvement and low risk of postinflammatory hyperpigmentation (PIH) for atrophic acne scars and produced improvement in striae alba. **Conclusion:** The picosecond laser is safe and effective for many dermatological conditions.

Keywords: Picosecond, laser, dermatology, photomechanical, LIOB, human & medicine

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BACKGROUND

Lasers are one of the most important treatment modalities in dermatology. The actions of a laser begin with the absorption of the light by specific chromophores. Lasers interact with chromophores through several mechanisms, such as photochemical and photothermal interaction, photoablation, plasma-induced ablation, and photodisruption, which mainly depend on the fluence and pulse duration of the laser.[1–]

Early lasers worked by photothermal interaction and generally had pulse durations of 1 microsecond to 1 second. Nonselective photothermal interaction causes destruction of normal tissue and unwanted side effects.[2] The picosecond laser is developed with a shorter pulse duration, which confines the photothermal effects to the target and produces photomechanical effects and plasma induction.[5] Initially developed for tattoo removal, the picosecond laser showed efficacy in other disorders such as the nevus of Ota, Hori's macules, melasma, scars, and for rejuvenation.[6] There are various types of picosecond lasers, with different wavelengths, pulse durations and fractional modes.

REVIEW

The picosecond laser interacts with tissue via two mechanisms namely photomechanical or photoacoustic interaction or photo-thermo-mechanical disruption (PTMD), and laser-induced optical breakdown (LIOB).[6,7] Significant photomechanical interaction happens when pulse duration is less than stress relaxation time or inertial confinement time.[7,8]

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Short pulse duration reduces time to relax built-up pressure, resulting in effective conversion of light energy to acoustic energy and fractures of chromophores into smaller particles that are easier to remove by macrophages.[9] Shorter pulse duration also requires less energy to ablate the tissue, known as "cold ablation".[10] Photomechanical interaction is the mechanism of action of non-fractional picosecond laser.[6,7]

LIOB starts with the appearance of accelerated seed electrons, which collide with surrounding molecules and release more free electrons. This process is called ionization or electron avalanche and produces a collection of free electrons called plasma. Plasma absorbs all incoming electromagnetic radiation, causing a loss of optics or an optical breakdown, and ablates tissues. LIOB in the skin is always followed by a mechanical process due to rapid plasma expansion or photodisruption. Photodisruption can be in the form of shockwave emission, cavitation bubble formation, or the recurrence of shockwaves upon bubble collapse, which can also ablate tissues.[7,11]

LIOB can be divided into thermionic emission initiated (or thermally-initiated) LIOB (TI-LIOB) or multiphoton absorption initiated (or multiphoton-initiated) LIOB (MI-LIOB). Both LIOB require irradiance higher than PTMD. MI-LIOB requires a laser with an irradiance above 10^{11} W/cm^2 and a picosecond pulse duration, strongly focused in a transparent or non-absorbing medium. A focused laser results in a high electric field and induces the absorption of multiple photons which provide the energy needed for ionization, the release of free electrons, the ionization avalanche, and plasma formation. MI-LIOB does not need absorption of photon by chromophores, and its location can be determined by focusing a laser into certain skin compartments, so this process is not affected by skin phototypes. On the other hand, TI-LIOB does not need a laser with high irradiance of strongly focused beam, but need rather strong absorption by the chromophore. A superheated chromophore undergoes thermal ionization, releasing electrons from their covalent bonds, called thermions. Thermion converts its energy into kinetic energy, becomes a free electron, and initiates plasma formation. TI-LIOB is chromophore dependent, and thus its location is determined by the distribution of chromophores and optical parameters such as laser wavelength and chromophore absorption spectrum.[7]

Histologic findings showed that melanin and hemoglobin act as main chromophores for LIOB formation after fractional picosecond laser exposure, and thus it can be estimated that fractional picosecond lasers operate by TI-LIOB. Spheric intraepidermal vacuoles were seen minutes after laser exposure, which were then filled with cellular debris and melanin within 24 hours. These vacuoles and debris were eliminated transdermally within 3-7 days. Dermal inflammation was seen within 24 hours and thought to be the effects of shockwaves to the dermis. Heat shock proteins were upregulated, and elastinase was downregulated, resulting in increased dermal collagen and elastin.[6,12]

Based on these mechanism of actions, picosecond laser may be applied in disorders requiring destruction of chromophores, such as tattoo removal and hyperpigmentations, and other collagen and elastin disorders, such as scars and aging skin.

Vachiramon et al. compared 532-nm picosecond and QS KTP lasers in solar lentigines in Asians and noted no difference in the clearance of lesions or rate of post inflammatory hyperpigmentation (PIH).[6] Yang et al. compared 755-nm picosecond and QS alexandrite lasers in a split-face study for freckles in Chinese women. Both lasers produce a comparable clearance rate of approximately 75%, but with a lower average fluence in picosecond laser compared to the QS laser, and similar rate of adverse effect.[13]

Artzi et al. studied 532-nmpicosecond Nd:YAG laser for café au lait macules (CALMs) in patients with Fitzpatrick II-IV skin types and noted 50 to 95% clearance in 15 out of 16 subjects after 1 to 4 sessions with a 4 to 8 week interval and no response in 1 subject. Side effects include erythema, edema, and mild pain. Partial recurrence was seen in two subjects.[14]

Wang et al. compared 3 and 5 sessions of fractional 755-nm picosecond alexandrite laser and triple combination creams containing hydroquinone, fluocinolone acetonide, and tretinoin for melasma in Taiwanese and noted similar improvements in MASI in all groups. Lyons, Choi, and Chalermchai compared the combination of topical treatment and picosecond Nd:YAG laser with topical treatment alone in three split-face studies on melasma. In all studies, the side which received combination treatment improved more and with mild side effects.[6] In one study, recurrence was observed in 76.92% of side treated with combination therapy and 69.23% of side treated with topical treatment alone.[15] Lee et al. compared 755-nm picosecond alexandrite laser with 1064-nm QS Nd:YAG laser for dermal and mixed melasma in Asians, with better and earlier clearance in the picosecond laser-treated side.[6] Some of the above-mentioned studies did not include the type of melasma as inclusion criteria, which may affect the response to the treatment modalities used in the studies.

One randomized double-blind clinical trial compared 755-nm picosecond and QS alexandrite

lasers for nevus of Ota. Six laser sessions with a 12-week interval showed better clearance on the picosecond laser-treated side.[6] Yu et al. compared 755-nm picosecond and QS alexandrite lasers for acquired bilateral nevus of ota like macules (ABNOM) with 3 laser sessions and a-6 month interval and noted a better clearance rate of up to 97%, less pain, and shorter downtime with picosecond laser. PIH was less in picosecond laser, but the absolute value was high (28%). Kaur et al. compared the results of a study with a picosecond alexandrite laser and another study with an Er:YAG and QS Nd:YAG lasers combination for ABNOM. Complete clearance was noted in 76.7% and 100% of subjects treated with picosecond laser and combination lasers, respectively. PIH was 27.7% in the study using picosecond laser and none in study using combination lasers. However, there were only five subjects in the study with combination lasers.[16]

Picosecond laser has good efficacy and safety for solar lentigines and freckles, but the superiority to QS laser is not yet clear, and other factors such as cost must also be considered.[6] Picosecond laser also has good efficacy and safety for cafe-au-lait macules (CALM).[14] Picosecond laser may be considered as an additional treatment for moderate to severe melasma in combination with other topical, systemic, or laser treatments. Picosecond laser can be considered as a first-line treatment for Nevus of Ota and ABNOM.[6]

Pinto et al. and Zhang et al. compared picosecond alexandrite and Nd:YAG lasers and QS Nd:YAG laser for black tattoos and blue-black eyeliner tattoos, and noted similar efficacy in terms of tattoo clearance and the number of sessions required for both lasers, but with less pain with the picosecond laser.[6] Lorgeou et al. and Choi et al. compared picosecond alexandrite and Nd:YAG laser and QS Nd:YAG lasers and noted better efficacy with picosecond laser.[6,17] Choi et al. also showed that wavelength is more influential than pulse duration in the removal of certain colors of tattoos. However, with the same wavelength and tattoo color, picosecond laser was more efficacious than QS laser.[17] Picosecond laser is currently the gold standard and first-line treatment for tattoo removal of almost all colors.[6] There are two conditions in which QS laser may be better than picosecond laser in tattoo removal, namely when QS laser has much higher fluence and a more optimal wavelength for certain tattoo colors than picosecond laser.[18] The combination of a picosecond laser and a CO_2 laser has better efficacy.[19]

Sierra et al. showed that fractional 755-nm picosecond alexandrite laser is more effective and safe than fractional 1927-nm thulium fiber laser , while Wu et al. showed that fractional 1064-nm picosecond Nd:YAG laser is as effective and safe as fractional 1927-nm thulium fiber laser for photoaging. Both studies showed lesser downtime with fractional picosecond laser.[6,20] Nakano showed that picotoning with nonfractional 1064-nm picosecond Nd:YAG laser improved skin firmness and dermal reconstruction, and fractional 1064-nm picosecond Nd:YAG laser improved crepe-like wrinkles, skin moisture, and epidermal and dermal reconstruction.[21] Kirsanova et al. showed that high-fluence fractional 1064-nm picosecond Nd:YAG laser provided better clinical and histological result but more downtime than low-fluence group in treating photoaging.[22] Picosecond laser has similar or better efficacy compared to other non ablative lasers for photorejuvenation and may be beneficial in cases requiring special attention such as in pigmented skin, PIH, melasma, or infraorbital hyperpigmentation.[20]

Chayavichitsilp et al. showed that fractional 1064-nm picosecond Nd:YAG laser and fractional 1550-nm erbium fiber laser provided similar improvement (33-38%) in atrophic acne scars in patients with Fitzpatrick III-IV skin types. Pinpoint bleeding is more common, but pain is less on the picosecond laser side.[6] Kwon et al. showed that fractional picosecond Nd:YAG laser 1064 nm provided better efficacy (54.6% vs. 41.9%), faster results, and less pain than fractional 1550-nm erbium glass laser in atrophic acne scars in patients with Fitzpatrick III-IV skin types.[23] Tantrapornpong compared fractional 1064-nm picosecond Nd:YAG laser to fractional 10600-nm CO_2 laser in mild-to-moderate atrophic acne scars and noted similar efficacy in both lasers but less pain, downtime, and PIH in picosecond laser side.[24] Fractional picosecond laser showed moderate improvement and a low risk of PIH for atrophic acne scars. Picosecond laser may be considered in mild-to-moderate acne scar patients who wish for minimal downtime, have failed more established treatments, have pigmented skin, or have postacne hyperpigmentation or erythema.[6,25]

Zaleski-Larsen et al. compared fractional 1064 and 532-nm Nd:YAG laser with fractional 1565-nm erbium fiber laser for striae alba and noted similar improvements in texture (31%) and atrophy (30-35%) with no significant side effects.[26]

Choi et al. studied picosecond Nd:YAG laser 1064 nm for hypertrophic scars and noted moderate (25-49%) improvement in Global Assessent Scoring and a significant decrease in the Vancouver Scar Scale. Pain and erythema were noted in 20.8% and 4.8% of patients.[27] Further study is required, and picosecond laser can be considered as an additional treatment and combined with other established treatments for hypertrophic scars.[6]

DISCUSSION

Picosecond laser is safe and effective for many dermatological conditions. A systematic review from Wu et al. showed that picosecond laser can be a first-line treatment for tattoo removal, nevus of Ota, and ABNOM. Picosecond laser has comparable efficacy and safety to other lasers for pigmentary disorders such as solar lentigines, freckles, and melasma, and disorders of collagen and elastin production such as photoaging, atrophic acne scars, and striae alba. Picosecond laser may be considered as an additional treatment for hypertrophic scars.[6]

Table 1. Advantage and disadvantage of picosecond laser compared to other lasers[6,9,13–16,20,25]

Advantages	Disadvantages

• Predominant photomechanical interaction
• Two modes of action:
  • Nonfractional to destroy chromophores
  • Fractional to increase collagen and elastin
• Better efficacy:
  • Less sessions for tattoo removal
  • Better clearance for nevus of Ota and ABNOM
  • Ability to treat atrophic and hyperpigmented scars together
• Better safety profile
  • Shorter downtime
  • Generally less painful
  • Lower incidence of PIH
	• Generally more expensive
	• Possible recurrence of melasma and CALM

ABNOM = acquired bilateral nevus of Ota-like macules; CALM = Café-au-lait macules; PIH = post-inflammatory hyperpigmentation

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