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Laser Treatment of Dark Skin

An Updated Review

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Contents

Abstract

The growing diversification of the patient population coupled with the increasing demand for cosmetic laser rejuvenation has highlighted the need to develop cutaneous laser systems and establish treatment protocols for patients with a wide range of skin conditions and phototypes. Recent technologic advancements have provided viable treatment options to achieve clinical outcomes that were previously only attainable in patients with lighter skin tones. This review provides an updated discussion of the range of laser treatments available for pigmented skin and sets the stage for further advancements.

Pigment-specific laser technology with green, red, or near-infrared light targets a variety of pigmented lesions such as lentigines, ephelides, café-au-lait macules, and melanocytic nevi as well as tattoos and unwanted hair. Short-pulsed alexandrite, ruby, and neodymium:yttrium-aluminum-garnet (Nd:YAG) lasers are used for pigmented lesions and tattoos, whereas their longer pulse-width laser counterparts are used for laser-assisted hair removal. Vascular lesions and hypertrophic scars can be treated with a variety of vascular-specific lasers, but it is the pulsed dye laser (PDL) that has long been the gold standard treatment for these lesions due to its high specificity for hemoglobin and its ability to improve skin surface texture in children and adults.

Laser skin resurfacing techniques for photodamaged skin and atrophic scars have been optimized with fractional technology to produce excellent clinical outcomes and minimal complication risks. Radiofrequency and nonablative lasers are also used to provide skin tightening and collagen remodeling with virtually no postoperative recovery.

Of the estimated 12.1 million cosmetic surgical procedures performed in the US in 2008, 25% were performed on racial and ethnic minorities, an increase of 11% over 2007.[1] Laser and light treatments rank in the top five most requested procedures in annual surveys of cosmetic and dermatologic surgeons.[1,2] Recent US population statistics reveal dramatically shifting demographics that would anticipate a likely increase in this percentage. As of 2008, Asians, Hispanics, and African Americans accounted for 31% of the US population.[1] US Census Bureau data projects that by 2050, people of color are expected to become the majority, comprising 54% of the US population, with Latinos accounting for 30%, African Americans 15%, and Asians 9.2%.[3] The rising popularity of cutaneous laser surgery as an accepted therapy for various skin pathologies, coupled with the diversification of the patient population, has led to increased demand for laser treatment of darker skin tones. Despite the increasing shift towards a US population represented by darker ethnic skin types, current literature regarding the use of lasers in darker skin types is limited.

The unusually wide absorption spectrum of melanin (ranging from 250 to 1200 nm) renders most visible-light and near-infrared dermatologic lasers capable of specifically targeting pigment. However, nonspecific energy absorption by relatively large quantities of melanin in the basal layer of the epidermis in darkly pigmented patients can increase nonspecific thermal injury and lead to a higher risk of untoward effects, including permanent dyspigmentation, textural changes, focal atrophy, and scarring. Moreover, competitive absorption by epidermal melanin substantially decreases the total amount of energy that can reach deeper dermal lesions, making it more difficult to achieve the degree of tissue destruction necessary to produce the desired clinical result. Although difficult and associated with a relative overall greater risk of complications, effective laser therapy in patients with darker skin phototypes can be achieved.[4-7] When determining a treatment protocol for an individual patient, selecting the proper laser energy and wavelength is important in ensuring a substantial margin of safety while still producing satisfactory results. Highly melanized skin absorbs electromagnetic energy much more efficiently than fair skin, yet the absorption coefficient of melanin decreases exponentially as wavelengths increase.[8] The darkest skin (Fitzpatrick phototype VI) may absorb as much as 40% more energy when irradiated by a visible light laser than does lighter (type I or II) skin when fluence and exposure duration remain constant.[8] As such, epidermal melanin absorbs approximately four times as much energy when irradiated by a 694 nm ruby laser as when exposed to the 1064 nm beam generated by a neodymium:yttrium-aluminum-garnet (Nd:YAG) laser.[8] In general, longer wavelength systems that are less efficiently absorbed by endogenous melanin and can penetrate more deeply into the dermis should be employed at the minimal threshold fluence necessary to produce the desired tissue effect in a given individual (as determined through irradiation test spots) in order to minimize the extent of collateral tissue damage.[9] A prudent approach to treatment is far preferable to incurring the risk of irreparable tissue destruction resulting from excessive thermal injury.

1. Pigmented Lesions

Pigment-specific laser technology employs green, red, or near-infrared light to selectively target intracellular melanosomes of pigmented lesions such as lentigines, ephelides, café-au-lait macules, nevus of Ota, and melanocytic nevi. Pigment-specific lasers are also used to eradicate unwanted hair by damaging follicular structures where melanin is heavily concentrated (table I).

Quality- or Q-switched (QS) systems emit maximum energy output in nanosecond (ns) pulses that are substantially shorter than the 100 ns thermal relaxation time of melanosomes. They have long represented the safest means to treat pigmented lesions due to their ability to limit injury to the targeted melanosomes and thus avoid undesirable pigmentary changes.[10] QS systems currently available include the 532 nm frequency-doubled Nd:YAG, 694 nm ruby, 755 nm alexandrite, and 1064 nm Nd:YAG lasers. The absorption peaks of melanin lie in the UV electromagnetic range, with decreased absorption capacity at the longest wavelengths. Thus, the red and infrared wavelengths generated by the alexandrite and Nd:YAG laser systems exert their dermal effects independent of epidermal melanin content and can, thus, yield more effective treatment of pigmented dermal lesions and hair follicles. The use of longer pulse durations and intense pulsed light (IPL) systems has also shown good clinical effects.[11,12]

When targeting any pigmented lesion, treatment should always be initiated at threshold fluence. This is clinically achieved when either immediate lesional whitening or a sensation of warmth in the treatment area is evident, signifying laser energy absorption and heat or shockwave generation within the melanosomes. If the clinical threshold is exceeded, epidermal exfoliation and pinpoint bleeding ensues, resulting in blistering, possible temporary or permanent hypopigmentation, and the higher probability of skin textural changes or scarring.[13]

Even when optimal parameters are applied, one of the most common adverse effects associated with QS laser treatment in dark-skinned individuals is post-inflammatory hyperpigmentation (PIH). Although the exact mechanism for PIH is unknown, direct melanin stimulation following laser impact is thought to be involved. More recently, it has been speculated that QS laser irradiation stimulates fibroblasts by upregulating melanogenic stimulating factors such as fibroblast growth factors, hepatocyte growth factors, and stem cell factors, thereby increasing pigmentation. Given the mild and transient nature of PIH, QS laser therapy remains the most effective therapy for treating pigmented lesions in patients with dark skin.[12]

Of the pigmented lesions that disproportionately affect ethnic groups with darker skin phototypes, nevi of Ota and Hori macules have proven to be amenable to treatment with QS ruby, alexandrite, and Nd:YAG lasers[14-22] (figure 1). In a small percentage of treated patients, recurrence of pigment may be seen despite initially successful QS laser therapy. This can be

Table I. Dermatologic lasers in dark skin

Lesion	Laser	Wavelength (nm)
Pigment		
lentigo, café-au-lait macule, nevus of Ota, benign melanocytic nevi	QS ruby	694
	QS alexandrite	755
	QS Nd:YAG	532/1064
Tattoo		
black/blue ink	QS ruby	694
	QS alexandrite	755
	QS Nd:YAG	1064
red/orange/yellow ink	QS Nd:YAG (frequency-doubled)	532
Hair (brown/black)	LP ruby	694
	LP alexandrite	755
	LP diode	800
	LP Nd:YAG	1064
	IPL	550–1200
Vascular		
port-wine stain, hemangioma, telangiectasias	PDL	585–595
	LP alexandrite	755
	LP Nd:YAG	1064
Scars		
hypertrophic/keloid	PDL	585
atrophic	CO_2/Er:YAG (pulsed, fractional)	10 600/2940
	PDL, IPL, Nd:YAG, diode, erbium glass, erbium fiber	Various
Skin rejuvenation		
rhytides	CO_2/Er:YAG	10 600/2940
	PDL, IPL, Nd:YAG, diode, erbium glass, erbium fiber	Various
tightening	RF	N/A

CO_2 = carbon dioxide; **Er:YAG** = erbium:yttrium-aluminum-garnet; **IPL** = intense pulsed light; **LP** = long-pulsed (millisecond); **N/A** = not applicable; **Nd:YAG** = neodymium:yttrium-aluminum-garnet; **PDL** = pulsed dye laser; **QS** = quality-switched (nanosecond); **RF** = radiofrequency.

explained by incomplete lesional clearance that becomes evident after resolution of post-treatment skin blanching and/or further proliferation of residual pigment.[23] Because the pathogenesis and origin of the dermal melanocytes of Hori macules, although similar to nevus of Ota, are not as well understood, the formation of an optimal treatment plan for Hori macules is more challenging. The high frequency at which Hori macules coexist with other pigmented lesions also makes treatment of these lesions more difficult. Laser-associated PIH occurs more frequently and severely after treatment of Hori macules than it does with nevi of Ota, presumably due to distinctly different melanocyte populations between the two lesions. Recently, combined therapeutic approaches for Hori macules such as various pigment-specific laser treatments with chemical peels and/or IPL have been advocated. A combination approach may allow for greater dermal penetration and subsequent dermal pigment eradication, leading to a lower risk of PIH and improved clinical outcomes of these lesions.[24]

Melasma is another pigmented process that is difficult to resolve due to its complex etiology (hormonal, genetic, and UV exposure) and the role of PIH. Irradiation of melasma with any pigment-specific laser is highly unpredictable, ranging from a virtual lack of response to worsening of the dyschromia.[25] Although fractional 1550 nm photothermolysis has been found to provide some clinical improvement in the immediate treatment of melasma after four sessions at monthly intervals, it has limited long-term efficacy in dark-skinned patients.[26]

Dermatosis papulosa nigra is another benign pigmented lesion commonly associated with dark skin, but only a few

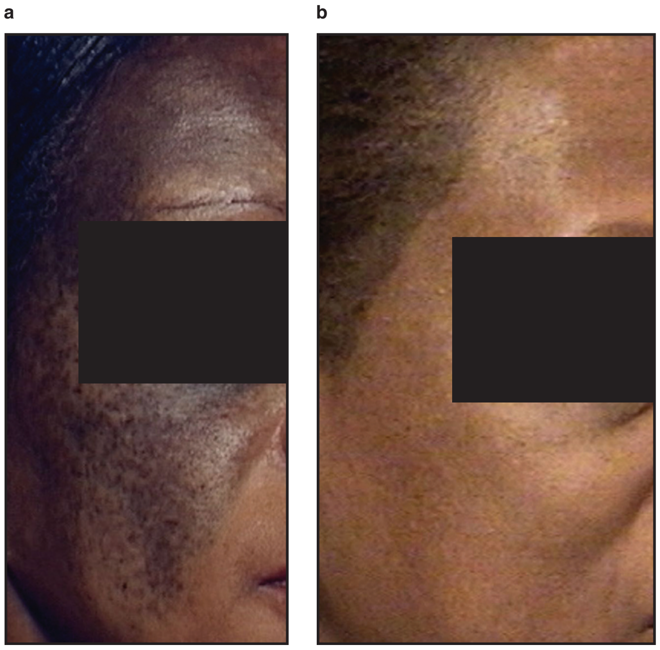

Fig. 1. Nevus of Ota before (**a**) and after six Q-switched alexandrite laser treatments (**b**).

investigations of the effect of laser treatment on this condition have been reported. The comparison of potassium-titanyl-phosphate (KTP) laser irradiation with electrodesiccation found the laser treatment to be a safe, effective, and well tolerated alternative for the treatment of dermatosis papulosa nigra in patients with dark skin, with the added advantage of being less painful.[27]

2. Tattoos

Laser technology has revolutionized the removal of unwanted tattoo pigment without scarring. Because multiple different inks are often present in a tattoo, effective treatment requires the use of various visible and near-infrared wavelengths.[28,29] Tattoos may respond unpredictably to laser treatment, not only because their chemical compositions are highly variable, but also because the tattoo inks are often located at variable dermal depths. The QS 694 nm ruby laser is highly efficacious in removing black and blue tattoo pigments; however, its wavelength is strongly absorbed by epidermal melanin and its potential for inducing long-term dyspigmentation or other untoward effects is relatively high in patients with darker skin tones.[30] The QS Nd:YAG or alexandrite laser are thus better choices for treating blue and black tattoo pigments in darker skin because energy is less well absorbed by epidermal melanin at 1064 nm and 755 nm wavelengths, respectively[31,32] (figure 2).

3. Hair

Several pigment-specific laser systems with relatively long (millisecond, ms) pulse durations and concomitant epidermal cooling capabilities have demonstrated safety and efficacy in removing unwanted hair in patients with darker skin phototypes.[33-47] While long-pulsed alexandrite and ruby lasers can be applied, the long-pulsed Nd:YAG laser has demonstrated the lowest incidence of adverse effects caused by nonspecific epidermal melanin absorption since its wavelength is more weakly absorbed by melanin than any other laser-assisted hair removal device currently available[41,44,45] (figure 3). Pseudofolliculitis barbae, a condition with a high incidence in the African American population has shown favorable response to laser-assisted hair treatment using either a long-pulsed diode[39] or Nd:YAG[46] system with minimal untoward sequelae. Pneumatic skin flattening is a new technology that has been shown to help control the pain during treatment and reduce post-treatment erythema without altering the efficacy of hair removal in patients with dark skin.[47]

The use of IPL as a safe and effective treatment for hair removal in patients with darker skin phototypes has also been well documented.[48-54] Most recently, a low-energy, pulsed-light device for home use was reported to have achieved marked hair count reduction in patients with a wide range of skin phototypes.[55]

4. Vascular Lesions and Hypertrophic Scars

Lasers generating green or yellow light with wavelengths ranging from 532 to 600 nm have been used successfully to treat a variety of vascular lesions, including port-wine stains, hemangiomas, and facial telangiectasias.[56,57] Pulsed dye laser (PDL) systems (585–595 nm) have long been considered the most

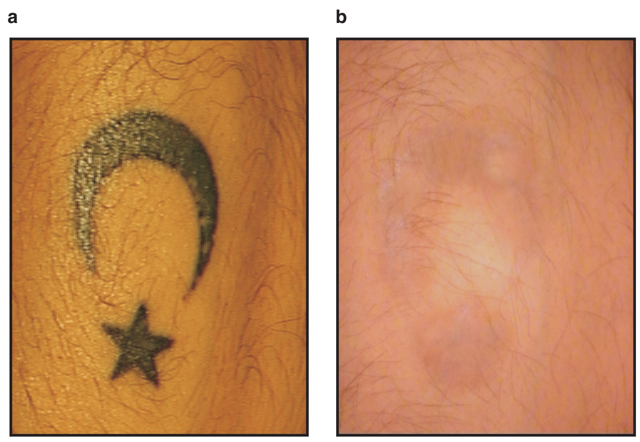

Fig. 2. Professional tattoo before (**a**) and after nine Q-switched alexandrite laser treatments (**b**).

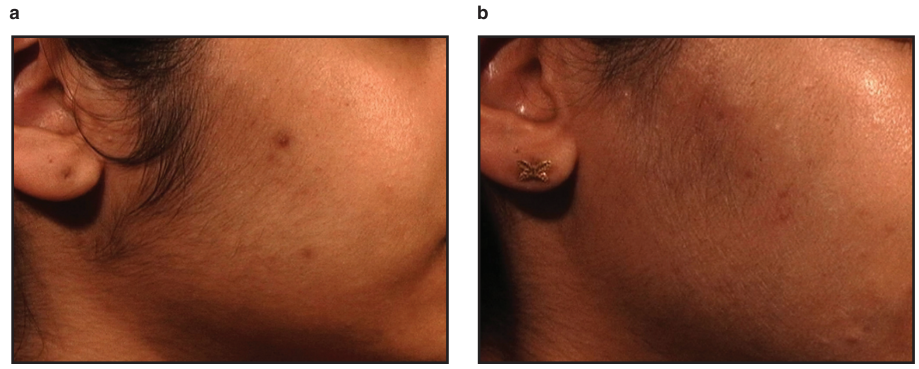

Fig. 3. Dark terminal facial hair before (**a**) and after three long-pulsed neodymium:yttrium-aluminum-garnet (Nd:YAG) laser treatments (**b**).

vascular specific given the fact that a major absorption peak of oxyhemoglobin occurs at 577 nm.[58,59] Early studies using PDL systems were limited to patients with lighter skin tones before further refinements in laser technology, development of epidermal cooling techniques, and expanded clinical protocols made treatment of darker skin tones safe and effective.[60-66]

Most recently, long-pulsed (ms) 1064 nm Nd:YAG lasers were introduced to better effect deep dermal penetration necessary for adequate treatment of large telangiectasias and reticular veins.[67] An added benefit of 1064 nm irradiation is its ability to treat skin independent of epidermal melanin content, thus effecting safe treatment in patients with darker skin tones.[68] These 1064 nm lasers also offer a viable treatment option for vascular birthmarks in patients with darker skin phototypes[69] and have been used successfully in combination with 595 nm PDL to more effectively treat recalcitrant port-wine stains.[70] Other laser systems (e.g. long-pulsed 755 nm alexandrite) have also been reported to improve vessels after a single treatment, but produce postoperative pigmentation in more than one-third of patients, presumably due to hemosiderin deposition and/or excessive cryogen cooling.[71]

PDL irradiation has additionally been proven effective in the treatment of hypertrophic scars and keloids, which occur more frequently among individuals with darker skin tones[72,73] (figure 4). Improvements in skin texture, bulk, and pliability of scars after PDL treatment have been reported.[74,75] The mechanisms whereby the vascular-specific PDL renders its effect on scars have not been fully elucidated, but plausible explanations include selective photothermolysis of vasculature, release of mast cell constituents (such as histamine and interleukins) that could affect collagen metabolism, and collagen fiber heating with disruption of disulfide bonds and subsequent collagen realignment.[75,76] A recent study demonstrated a PDL-induced reduction of transforming growth factor-β expression, fibroblast proliferation, and type III collagen deposition.[77]

While the presence of increased epidermal pigment in patients with darker skin tones interferes with the absorption by the targeted hemoglobin of vascular-specific laser energy, laser treatments can still be safely used. Relatively low PDL energy densities (4.5–5.0 J/cm^2, 10 mm spot) are typically applied to hypertrophic scars and keloids at 2-month time intervals. Transient PIH is the most common adverse effect of PDL treatment of vascular lesions and scars in pigmented skin.[56,73] Although patients with darker skin phototypes are more prone than those with fair skin to develop post-PDL pigmentary changes, epidermal skin cooling techniques can reduce the risk of dyspigmentation.

5. Atrophic Scars and Photodamaged Skin

Atrophic scarring and photoaging are common concerns and their treatment over the years has been a particular challenge in individuals with dark skin due to associated adverse effects and variable clinical responses. Several types of ablative and non-ablative lasers and other devices have been used to treat these lesions.[78] Skin resurfacing with either a high-energy, pulsed carbon dioxide or erbium:yttrium-aluminum-garnet (Er:YAG) laser has been the gold standard for eliciting the highest degree of clinical and histologic improvement since the mid-1990s.[79-83] These ablative laser systems work to selectively heat and vaporize superficial skin by emitting energy that is absorbed by intracellular tissue water. Use of the carbon dioxide laser for cutaneous resurfacing produces an additional skin tightening benefit through controlled heating of dermal collagen. While clinical benefits are numerous, the complete epidermal ablation effected by these systems results in loss of barrier function and is associated with a prolonged postoperative recovery period and extensive adverse effect profile including prolonged erythema, pigmentary alteration, infection and, in rare cases, scarring.[84] The risk and duration of these adverse effects are significantly a b

Fig. 4. Keloid scar before (**a**) and after four 585 nm pulsed dye laser treatments (**b**).

higher in patients with dark skin. Transient hyperpigmentation is the most common adverse effect experienced after laser skin resurfacing (affecting approximately one-third of all patients), with its incidence increasing to 70% or more among patients with the darkest skin phototypes.

In an effort to provide an alternative skin resurfacing treatment with decreased risk profile, various nonablative technologies that deliver laser or light-based energies with epidermal cooling were subsequently developed. The clinical effect of these red and infrared systems (including pulsed dye, IPL, Nd:YAG, diode, and erbium glass) on a wide range of skin types and conditions has been evaluated.[85-88] Modest improvement in skin texture (including scars and rhytides) is typically produced after a series of monthly treatments using any one of these devices. Adverse effects are limited to erythema and edema since no open wound is created.

Another nonablative technology that has been advocated for skin rejuvenation involves application of radiofrequency, which, unlike laser or light sources that generate heat when selected tissue absorbs photons, delivers an electric current that non-selectively generates heat by the tissue's natural resistance to the flow of ions.[89-91] Because energy absorption by melanin is not an issue, radiofrequency energy can be safely applied regardless of skin type. Heat-induced collagen denaturation and contraction account for the immediate skin tightening seen after treatment, with maximal clinical results evident after several months.

The latest laser skin resurfacing advancement (coined fractional photothermolysis) has married the advantages of ablative

a b

Fig. 5. Atrophic acne scars before (**a**) and after three nonablative fractional laser treatments (**b**).

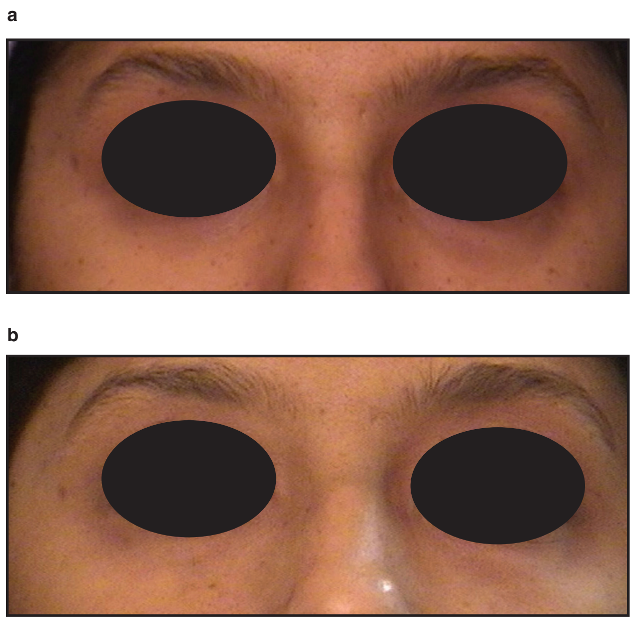

Fig. 6. Periocular rhytides and hyperpigmentation before (**a**) and after fractionated carbon dioxide laser treatment (**b**).

technology (including more pronounced clinical improvement) and nonablative technology (including reduced postoperative recovery rates and risk of complications).[92] Fractional lasers create discrete columns of microscopic thermal injury to the epidermis and dermis that leads to epidermal necrosis and collagen denaturation.[93,94] With nonablative fractional skin resurfacing, the tissue surrounding each microscopic treatment zone remains intact after treatment and rapid healing occurs from residual viable epidermal and dermal cells. No external wound is apparent and clinical improvement of scars, rhytides, melasma, and striae is typically observed after a series of monthly treatments[95-103] (figure 5). Treatment using ablative fractional laser technology produces a visible wound, but healing occurs rapidly from microscopically preserved areas such that re-epithelialization is completed within 5–7 days. Significant clinical benefit is achieved after a single treatment[104-107] (figure 6). The risk of adverse effects is significantly lower than non-fractional laser skin resurfacing due to the rapid postoperative recovery.[108-111]

6. Summary

The growing diversification of the patient population coupled with the increasing demand for cosmetic laser rejuvenation has highlighted the need to develop systems and establish treatment protocols for patients with a wide range of skin conditions and phototypes. Recent technologic advancements have provided viable treatment options to achieve clinical outcomes that were previously only attainable in patients with lighter skin tones. Continued refinements in current technology and introduction of novel devices are anticipated to have a positive impact in the field in the foreseeable future.

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