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Laser Treatment of Dark Skin: A Review and Update

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ABSTRACT

[AU: PLEASE PROVIDE ABSTRACT FOR ARTICLE]

POSSIBLE ABSTRACT:

Of the estimated 11.7 million cosmetic surgical and nonsurgical procedures performed in the United States (U.S.) in 2007, 22% were performed on racial and ethnic minorities.1 Laser and light treatments rank in the top five most requested procedures in annual surveys of cosmetic and dermatologic surgeons.

Recent U.S. population statistics reveal dramatically shifting demographics that would anticipate a likely increase in this percentage.

U.S. Census Bureau data projects that by 2050, people of color are expected to become the majority, comprising 54% of the U.S. population, with Latinos accounting for 30%, African Americans 15%, and Asians 9.2%. The rising popularity of cutaneous laser surgery as an accepted therapy for various skin pathologies, coupled with the diverse face of the patient population, has led to increased demand for laser treatment of darker skin tones.

Although difficult, effective laser therapy in patients with darker skin phototypes can be achieved. When determining a treatment protocol for an individual patient, the proper laser energy and wavelength are important in ensuring a substantial margin of safety while still achieving satisfactory results.

INTRODUCTION

Of the estimated 11.7 million cosmetic surgical and nonsurgical procedures performed in the United States (U.S.) in 2007, 22% were performed on racial and ethnic minorities.[1] Laser and light treatments rank in the top five most requested procedures in annual surveys of cosmetic and dermatologic surgeons.[1,2] Recent U.S. population statistics reveal dramatically shifting demographics that would anticipate a likely increase in this percentage. In 2007, the total number of individuals in the U.S. with darker skin phototypes was approximately 98 million.[1] U.S. Census Bureau data projects that by 2050, people of color are expected to become the majority, comprising 54% of the U.S. population, with Hispanics 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 diverse face of the patient population, has led to increased demand for laser treatment of darker skin tones.

Due to the unusually wide absorption spectrum of melanin (ranging from 250 to 1200 nm), all visible-light and near-infrared dermatologic lasers are capable of specifically targeting pigment. Nonspecific energy absorption by relatively large quantities of melanin in the basal layer of the epidermis in darkly pigmented patients; however, can increase unintended nonspecific thermal injury and lead to a higher risk of untoward side effects, including permanent dyspigmentation, textural changes, focal atrophy, and scarring. Moreover, competitive absorption by epidermal melanin substantially decreases the total amount of energy reaching deeper dermal lesions, rendering it more difficult to achieve the degree of tissue destruction necessary to affect the desired clinical result.[4,5]

Although difficult, effective laser therapy in patients with darker skin phototypes can be achieved. When determining a treatment protocol for an individual patient, the proper laser energy and wavelength are important in ensuring a substantial margin of safety while still achieving satisfactory results. Highly melanized skin absorbs electromagnetic energy much more efficiently than does fair skin, yet the absorption coefficient of melanin decreases exponentially as wavelengths increase.[6-9] Illustrating these principles, skin phototype VI may absorb as much as 40% more energy when irradiated by a visible light laser than does phototype I or II skin when fluence levels and exposure duration remain constant.[11] As such, epidermal melanin absorbs approximately four times as much energy when irradiated by a 694-nm ruby laser as when exposed to the 1,064-nm beam generated by a Nd:YAG laser, allowing greater penetration into the dermis.[10,11]

In general, longer wavelength systems that are less efficiently absorbed by endogenous melanin 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.[12] A prudent approach to treatment is far preferable to incurring the risk of irreparable tissue destruction resulting from excessive thermal injury.

Pigmented Lesions

Pigment-specific laser technology generates green, redor near-infrared light to selectively target intracellular melanosomes of pigmented lesions such as lentigines, ephelides, café-au-lait macules, nevus of Ota, melanocytic nevi, nevus spilus (also known as speckled lentiginous nevus [SLN]) and tattoo pigment. Pigment-specific lasers are also used to eradicate unwanted hair by damaging follicular structures in which melanin is heavily concentrated.

Quality- or Q-switched systems produce nanosecond (ns) pulses that are substantially shorter than the 100-ns thermal relaxation time of melanosomes. They have long represented the safest means for treating pigmented lesions due to their ability to limit unwanted injury to the prominent melanosomes and avoid undesirable pigmentary changes.[13] Q-switched systems currently available include the 532-nm frequency-doubled Nd:YAG, 694-nm ruby, 755-nm alexandrite, and 1,064-nm Nd:YAG lasers. The absorption peaks of melanin lie in the ultraviolet (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. Recently, the use of longer pulse durations and intense pulsed light (IPL) systems has also shown good clinical effects.[14,15]

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.[10]

Of the pigmented lesions that disproportionately affect ethnic groups with darker skin phototypes, nevi of Ota and Hori's macules have proved especially amenable to treatment with Q-switched ruby, alexandrite and Nd:YAG lasers[16-24]. In a small percentage of treated patients, recurrence of pigment may be seen despite initial successful Q-switched laser therapy. This can be explained by incomplete lesional clearance that becomes evident after resolution of post-treatment skin blanching and/or further proliferation of residual pigment.[25] Unlike the favorable clinical outcome from laser irradiation of nevi of Ota, melasma remains extraordinarily difficult to resolve due to its complex etiology (hormonal, genetic, and UV exposure) and the role of post-inflammatory pigmentation. Irradiation of melasma with any pigment-specific laser is highly unpredictable; ranging from a virtual lack of response to worsening of the dyschromia.[26]

Tattoos

Laser technology has revolutionized the ability to remove unwanted tattoo pigment. Because multiple different inks are often present in a tattoo, effective treatment requires the use of various wavelengths throughout the visible and near-infrared spectrum. Tattoos may respond unpredictably to laser treatment, not only because their chemical compositions are highly variable, but also because the tattoo inks are often placed in the deep dermis. The Q-switched 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 side effects is relatively high in patients with darker skin tones. Thus, the Q-switched Nd:YAG (1,064-nm) or alexandrite (755-nm) laser would be a better choice for treating blue and black tattoo pigments in darker skin since the energy is less well absorbed by epidermal melanin.[27-31]

Hair

Several pigment-specific laser systems with relatively long (millisecond) pulse durations and concomitant epidermal cooling capabilities have demonstrated safety and efficacy in removing unwanted hair in patients with darker skin phototypes[32-40]. Nd:YAG laser irradiation has demonstrated the lowest incidence of side 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.[40-43] 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[44] system with minimal untoward sequale.

The use of IPL as a safe and effective treatment for hair removal in patients with darker skin phototypes has also been well documented. [45-51] 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.[52]

Vascular Lesions and Scars

Vascular-specific laser systems include a wide array of Q-switched, pulsed, and quasi-continuous-wave lasers generating green or yellow light with wavelengths ranging from 532 to 600 nm. Since 577 nm represents a major absorption peak of oxyhemoglobin, the 585-nm flashlamp-pumped pulsed dye laser (PDL) has proven to be the most vascular-specific. For the treatment of port-wine stains, hemangiomas, and facial telangiectasias, the 585-nm PDL has garnered the best clinical track record for both effectiveness and safety, regardless of patient skin phototype. Similarly, the 595-nm-long PDL has shown excellent efficacy and safety profiles in the treatment of port-wine stains in Asians.[53]

The 585-nm PDL system has also proven effective in the treatment of hypertrophic scars and keloids, which occur more frequently among individuals with darker skin tones.[54] Hypertrophic scars are erythematous, raised, firm nodular growths that occur more commonly in areas subject to increased pressure or movement or in body sites that exhibit slow wound healing. The growth of these scars represents unrestrained proliferation of collagen during the wound-remodeling phase and is limited to the site of original tissue injury. They typically occur within one month of injury, may regress over time, and are histologically indistinguishable from other types of scars. In contrast to hypertrophic scars, keloids present as cosmetically disfiguring deep reddish-purple papules and nodules, most commonly on the earlobes, anterior chest, shoulders, and upper back. They proliferate beyond the boundaries of the initial wound, often continue to grow without regression, and are characterized histologically as thickened bundles of hyalinized acellular collagen haphazardly arranged in whorls and nodules with an increased amount of hyaluronidase. Keloids may develop weeks or years after the inciting trauma or even arise spontaneously without a history of preceding integument injury.[55]

The presence of increased epidermal pigment in patients with darker skin tones interferes with the targeted hemoglobin's absorption of vascular-specific laser energy. Still, darker-skinned patients can be treated safely with lasers. In general, hypertrophic scars and keloids are treated with low energy densities ranging from 6.0 to 7.5 J/cm^2 when using a spot size of 5 or 7 mm and 4.5 to 5.5 J/cm^2 when using a spot size of 10mm. Pulse durations ranging from 0.45 to 1.5 ms are commonly used. These intraoperative energy densities are typically lowered by at least 0.5 J/cm^2 in patients with darker skin to avoid postoperative sequelae.[56] Consequently, the clinical response to laser treatment may be reduced and additional treatment session may be necessary to treat patients with darker skin tones. Laser treatments are typically repeated at six-to-eight week (or longer) intervals. Most hypertrophic scars will improve by approximately 50% after two treatments with the PDL using the aforementioned laser parameters. Keloids often require more treatment sessions to achieve significant improvement, but some may prove unresponsive altogether.[57]

Transient post-inflammatory hyperpigmentation is the most common side effect of PDL treatment of vascular lesions and scars in pigmented skin.[58,59] Although patients with darker skin phototypes are more prone than those with fair skin to develop pigmentary changes after PDL treatment, skin cooling techniques can reduce the risk of dyspigmentation.[60,61] Hyperpigmentation often resolves within two-to-three months, as does transient hypopigmentation. The optimal duration and type of cooling (e.g., cryogen spray, forced air, contact chill tip) varies from system to system. Permanent hypopigmentation and scarring are rare. The side effect profiles for the 532 nm frequency-doubled Nd:YAG and potassium-titanyl-phosphate (KTP) lasers are similar, but side effects resulting from nonspecific epidermal injury in darker skinned patients are generally more common.[62-65] Investigators found that, while the 578 nm copper vapor laser could improve port-wine stains in patients with skin phototypes III–IV, a significant degree of epidermal injury resulted from laser treatment.[6,66]

In 1998, long-pulsed (millisecond) 1,064 nm lasers were introduced in an effort to target violaceous leg telangiectasia and large-caliber subcutaneous reticular veins.[67] The benefit of this wavelength is deep penetration of its energy independent of epidermal melanin content, thus effecting safe treatment in patients with darker skin tones. These millisecond-domain 1,064 nm lasers also offer a viable treatment option for vascular birthmarks in patients with darker skin phototypes[68] and have been used successfully in combination with 595nm PDL to more effectively treat recalcitrant port-wine stains.[69] Other laser systems (e.g., long-pulsed 755 nm alexandrite) also have been reported to improve vessels after a single treatment, but produce post-operative pigmentation in more than one-third of patients, presumably due to hemosiderin deposition and/or excessive cryogen cooling.[70]

Photodamaged Skin

Cutaneous laser resurfacing can provide an effective means for improving the appearance of diffuse dyschromia, photoinduced rhytides, and atrophic scarring in patients with darker skin phototypes. In the past, skin resurfacing with either a high-energy, pulsed CO_2 or erbium:yttrium-aluminum-garnet (Er:YAG) laser remained the gold standard technology for eliciting the highest degree of clinical and histologic improvement.[71] Energy emitted by these ablative lasers is absorbed by intracellular water, rapidly heating and vaporizing relatively superficial tissue.[72] Use of the CO_2 laser for skin resurfacing yields an additional benefit of collagen tightening through heating of dermal collagen. Plasma skin regeneration (PSR) is an alternative ablative option involving the use of ionized energy to generate plasma that thermally heats tissue when applied to the skin.[73] PSR can produce considerable skin tightening and textural improvement similar to single-pass CO_2 laser resurfacing when set at ablative energy settings (3–4 J).[74] Complete epidermal ablation effected by these systems; however, results in loss of barrier function and is associated with an extended postoperative recovery period and untoward side effects including erythema, pigmentary alteration, infection, and, in rare cases, fibrosis.

The risk and duration of side effects from ablative resurfacing are greater in patients with dark skin.[75] Transient hyperpigmentation is the most common side effect experienced after laser skin resurfacing (affecting approximately one-third of all patients), with the incidence rising to 68% to 100% among patients with the darkest skin phototypes (>III). Hypopigmenta-

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tion, on the other hand, is observed less frequently but tends to be long-standing, delayed in its onset (more than six months post procedure), and difficult to treat.[76]

Nonablative technologies that deliver laser, light-based, or radiofrequency energies to the skin may prove a more satisfactory compromise between efficacy and safety in patients with darker skin tones and were the focus of a shift away from ablative techniques for several years. A myriad of systems with "subsurfacing" capabilities has been studied in darker skin, including pulsed dye and IPL, Nd:YAG, diode, and Er:glass lasers[77-80]. Typically, a series of monthly treatments is delivered in which controlled thermal injury is generated in the dermis with subsequent inflammation, cytokine up-regulation and fibroblast proliferation. Modest improvement in skin coarseness, irregular pigmentation, pore size, telangiectasia, collagen remodeling and rhytides is typical after a series of treatments.

Unlike laser or light sources, which generate heat when selective targets such as oxyhemoglobin and pigment absorb photons, application of radiofrequency to the skin delivers an electric current that nonselectively generates heat by the tissue's natural resistance to the flow of ions. Because melanin absorption is not an issue, the radiofrequency device can be safely applied regardless of skin type. To prevent epidermal ablation, either contact or cryogen spray cooling is delivered before, during, and after the emission of radiofrequency energy. Heat-induced collagen denaturation and contraction account for the immediate skin tightening seen after treatment with maximal clinical results evident several months thereafter.[81-82] Electro-optical synergy is another technique that has emerged in an attempt to address the limitation of traditional light-based systems. Such systems combine the use of RF with either the diode laser or IPL as its optical energy source. The optical energy emitted preheats dermal structures and creates a temperature differential between targeted structures and surrounding tissues that may be exploited to allow for directed application of RF energy to dermal chromophores with less impedance. The optical energy levels are lower than those used in traditional light-based systems, thereby enabling potentially safer treatments in darker skin types.[83]

One of the latest technologies introduced for laser skin resurfacing involves a 1,550 nm erbium-doped mid-infrared fiber laser with a sophisticated optical tracking handpiece to create minute columns of thermal injury in the dermis. These microscopic treatment zones depict localized epidermal necrosis and collagen denaturation. Because the tissue surrounding each microscopic treatment zone is intact, rapid healing occurs from residual viable epidermal and dermal cells. The process has been termed fractional photothermolysis and it has been applied successfully to improve rhytides, atrophic scars, striae distensae, and dyschromia without significant risk of side effects.[84-89] This latter fact has been particularly useful in treatment of photodamaged skin in patients with dark skin. A retrospective chart review was conducted of 961 consecutive 1,550 nm erbium-doped laser treatments in 422 patients (skin phototypes I-V) in order to determine the short-and long-term side effects and complications associated with fractional photothermolysis in a large cohort of patients. The overall short-term complication rate was 7.6% and side effects were evenly distributed among different age groups, body locations, cutaneous conditions and skin phototypes, with the exception of postinflammatory hyperpigmentation, which was observed with increased frequency in patients with darker skin and lasting a mean of 50.7 days.[90] It has been proposed that use of higher treatment densities is more likely to produce swelling, redness and hyperpigmentation in darker skin phototypes than would the use of high treatment fluences.[91]

Despite minimal postoperative recovery and side effects associated with the 1,550-mm erbium infrared laser, results are not comparable to the dramatic improvement produced by traditional ablative lasers. Fortunately, technology is already advancing to meet this challenge. Ablative fractional resurfacing (AFR) combines the theory of nonablative fractional thermolysis with CO_2 ablation.[92] Studies regarding the use of such novel AFR devices are limited, but will undoubtedly be the focus of laser skin resurfacing in the near future.[93-95]

DISCLOSURES

The authors have no disclosures pertinent to this paper.

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