Laser Surgery in Dark Skin

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Although challenging, effective laser surgery in patients with darker skin tones can be achieved despite a higher inherent risk of side effects. Although the incidence of undesirable postoperative sequelae has decreased with the development of advanced laser technology and individualized treatment parameters, these risks may never be eliminated completely. Consequently, thorough patient preoperative preparation and education regarding the risks of cutaneous laser therapy will remain an essential component of treatment in darkly pigmented patients. In the future, as more refined laser techniques evolve, the ability to safely and effectively treat these patients will improve.

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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 increasing demands for researchers to investigate laser treatment of darker skin tones. Population statistics of the United States reveal dramatically shifting demographics in the past decade. Between 1990 and 2000, Hispanics and Asians accounted for 40% of the total growth of the U.S. population, African Americans for 12%, and non-Hispanic Caucasians for slightly over 2%.[1] In 2000, the total number of individuals in the United States with skin of color was approximately 85 million.[1] Despite the increased demand for dermatologic laser surgery by Asians, Hispanics, and African Americans, most of the current literature remains devoted to examining laser procedures performed on individuals with fair skin tones (Fitzpatrick skin phototypes I–II) and protocols have largely been defined on the basis of the more extensive clinical experience that has accumulated surrounding these patients.

Owing to its unusually wide absorption spectrum ranging from 250 to 1200 nm, melanin can be specifically targeted by all visible-light and near-infrared dermatologic lasers currently in use. Nonspecific energy absorption by relatively large quantities of melanin in the basal layer of the epidermis 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 in the darkly pigmented patient. 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 effect the desired clinical result. Treatment parameters, therefore, must be carefully considered when performing laser surgery on patients with darker skin phototypes.[2,3]

Although difficult, effective laser therapy in patients with darker skin phototypes can be achieved, since the absorption coefficient of melanin decreases exponentially as wavelengths increase.[4–8] Illustrating this principle, 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 the Nd:YAG laser, thus allowing greater penetration of the longer wavelength into the dermis.[9] Therefore, laser systems generating wavelengths that are less efficiently absorbed by endogenous melanin can often provide a greater margin of safety while still achieving satisfactory results.[10]

When determining a treatment protocol for an individual patient, power level is as important as the

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laser wavelength chosen when treating darker skin since highly melanized skin absorbs electromagnetic energy much more efficiently than fair skin. For example, 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] Thus, conservative power settings (the minimal threshold fluences necessary to produce the desired tissue effect in a given individual as determined through irradiation test spots) should be employed initially to minimize the extent of collateral tissue damage. Clearly, a prudent approach to treatment is far preferable to incurring the risk of irreparable tissue destruction resulting from excessive thermal injury.

Vascular-Specific Lasers

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. This system has also proven effective in the treatment of hypertrophic scars and keloids which occur more frequently among individuals with darker skin tones (Figure 1).[12] Similarly, the 595-nm-long PDL has shown excellent efficacy and safety profiles in the treatment of port-wine stains in Asians.[13]

Transient postinflammatory hyperpigmentation is the most common side effect of PDL treatment of port-wine stains in pigmented skin.[14,15] 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.[16,17]

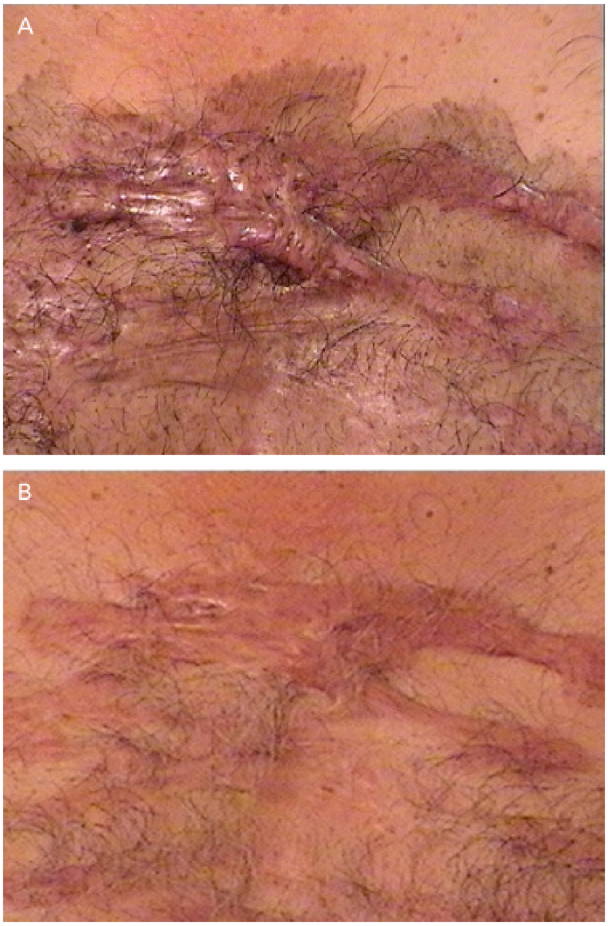

Figure 1. Keloid scar on the chest of a 50-year-old man from India (skin phototype IV) before (A) and after fourth treatment with a 585 nm pulsed dye laser (B).

Hyperpigmentation often resolves within 2 to 3 months, as does transient hypopigmentation. 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.[18–21] 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.[4,5]

In 1998, long-pulsed (millisecond) 1,064-nm lasers were introduced in an effort to target violaceous leg telangiectasia and large-caliber subcutaneous

Figure 2. Port-wine stain on the face of a 40-year-old woman with skin phototype V–VI before (A) and after 10 long-pulsed 1,064-nm Nd:YAG laser treatments (B).

reticular veins.[22] The benefit of this wavelength is deep penetration of its energy due to relatively low absorption by melanin, 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[23] (Figure 2). Other laser systems (e.g., long-pulsed 755-nm alexandrite) improved, but did not clear, vessels after a single treatment. More than one-third of the patients presented with posttreatment hyperpigmentation.[24]

Pigment-Specific Lasers

Pigment-specific laser technology generates green, red, or near-infrared light to selectively target intracellular melanosomes or tattoo pigment. Pigment-specific lasers are also used to eradicate unwanted hair by damaging follicular structures in which melanin is heavily concentrated.

Although quality- or Q-switched systems generating nanosecond (ns) pulses that are substantially shorter than the 10- to 100-ns thermal relaxation time of melanosomes have long represented the safest means for treating pigmented lesions due to their ability to limit unwanted injury to the prominent melanosomes in these patients and, thus, avoid undesirable pigmentary changes,[25] recent research has shown good clinical effects with the use of longer pulse durations and intense pulsed light (IPL) systems as well.[26,27] 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. Although melanin absorbs energy throughout the electromagnetic spectrum, its absorption peaks lie in the ultraviolet range, with decreased absorption capacity at the longest wavelengths. Thus, the far-infrared wavelengths generated by the alexandrite and Nd:YAG laser systems are less efficiently absorbed by epidermal melanin, which limits the extent of unwanted thermal injury to nontargeted tissues of the epidermis and upper papillary dermis. This, in turn, allows for deeper dermal penetration, making the effective treatment of pigmented dermal lesions and hair follicles possible. Whether targeting superficial epidermal lesions such as lentigines, ephelides, café-au-lait macules, or lesions with a deep dermal component such as nevus of Ota, melanocytic nevi or nevus spilus, treatment should be initiated at threshold fluence (the minimum energy necessary to produce immediate lesional whitening signaling the destruction of intracellular melanosomes). If the clinical threshold is exceeded, epidermal exfoliation and pinpoint bleeding ensues, resulting in blistering, possible temporary or permanent hypopigmentation, and perhaps even skin textural changes or scarring.[9]

Of the pigmented lesions that disproportionately affect ethnic groups with darker phototypes, nevi of

Figure 3. Nevus of Ota in a 52-year-old woman with skin phototype V before (A) and after six Q-switched 755-nm alexandrite laser treatments (B).

Ota have proved especially amenable to treatment with Q-switched ruby, alexandrite, and Nd:YAG lasers.[28–31] Of these systems, the alexandrite laser appears to offer distinct advantages over other modalities as its longer wavelength produces less epidermal damage than does the ruby laser and, since it requires lower fluences than does the Nd:YAG, less tissue splatter is produced intraoperatively[30,31] (Figure 3). In a small percentage of treated patients, recurrence of pigment may be seen despite initial successful Q-switched laser therapy, but could well be explained by incomplete lesional clearance that becomes evident after resolution of posttreatment skin blanching and/or further proliferation of residual pigment.[32]

In a recent study evaluating suitable therapy for freckles and lentigines in Asians, Wang and coworkers[33] found the Q-switched alexandrite laser better than IPL for freckles and the IPL better for lentigines. Hori's macules, also known as acquired bilateral nevus of Ota-like macules, are characterized clinically as bilateral, confluent, or reticulate blue-brown or slate-gray dyspigmentation most commonly involving the malar region in Asians.[34] In contradistinction to nevus of Ota, Hori's macules (which develop in adulthood) are bilateral and do not involve mucosa. Improvement of Hori's macules has been documented after treatment with Q-switched ruby,[35] alexandrite,[36] Nd:YAG,[37,38] or combination (532/1,064-nm Nd:YAG)[39] lasers. Transient postinflammatory hyperpigmentation occurs after laser treatment in most patients despite the pretreatment use of topical hydroquinones.[38,39]

Melasma appears as a scattering of lightly or darkly hyperpigmented macules and patches over the centrofacial, malar, and mandibular regions. Involvement may be limited to the epidermis or extend deeply into the dermis. Its response to irradiation with any pigment-specific laser is highly unpredictable; a virtual lack of response, worsening of the dyschromia, and recurrence are the too-frequent outcomes, especially among patients with darker complexions.[40] It is an extraordinarily difficult disorder to resolve because its etiology is multifactorial: hormonal factors, excessive ultraviolet light exposure, and genetic predisposition are among the causes most often cited as responsible for the condition.

The Q-switched ruby laser has been used in an attempt to treat melasma, but was found to produce immediate melanosomal rupture with fluence-related injury to epidermal and dermal pigment-containing cells, which in turn led to further skin darkening.[41] IPL has been used for refractory melasma, as have superficial ablative laser systems (e.g., 2,940-nm erbium:YAG and 1,550-nm erbium fiber).[42–45] These latter laser systems are capable of ablating epidermal tissue while producing minimal

Figure 4. Tattoo in a 17-year-old woman with skin phototype V before (A) and after third Q-switched 755-nm alexandrite laser treatment (B).

zones of dermal necrosis. While not pigment-specific, they may well exhibit a greater margin of safety when treating melasma due to the limited thermal injury they produce, substantially decreasing the likelihood of serious long-term side effects. Despite recent advances, however, treatment of melasma with lasers remains unpredictable, rendering definitive treatment protocol design difficult.

Laser technology has greatly enhanced the ability to remove unwanted tattoo pigment. Because multiple different pigments 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. As described previously, systems that generate energy characterized by longer wavelengths cause less collateral epidermal damage and penetrate more deeply, affording a safer and usually more effective form of treatment.[46] Although the Q-switched 694-nm ruby laser is highly efficacious in removing black and blue tattoo pigments, 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[46–50] (Figure 4). While an uncommon practice, epidermal ablation with a resurfacing laser may enhance the safety and effectiveness of tattoo removal in patients with darker phototypes by eliminating the problem of competitive melanin absorption.[47]

The combination of longer wavelengths, active epidermal cooling, and longer pulse durations provided by the most advanced laser technology has decreased the side effects after laser-assisted hair removal in patients with darker skin tones.[51–59] Several pigment-specific laser systems with relatively long (millisecond) pulse durations have demonstrated safety and efficacy in darker skin phototypes, including the 755-nm alexandrite,[53–56] 810-nm diode,[57,58] and 1,064-nm Nd:YAG.[59] IPL treatment of hirsutism in patients with darker skin phototypes may also be possible; however, studies have been limited.[60] Alster and colleagues[59] demonstrated significant long-term hair reduction after a series of three monthly long-pulsed 1,064-nm Nd:YAG laser treatments in 20 women with skin phototypes IV–VI (Figure 5). Adverse effects were limited to transient pigmentary alteration without fibrosis or scarring. Nd:YAG laser irradiation has demonstrated the lowest incidence of side effects caused by nonspecific

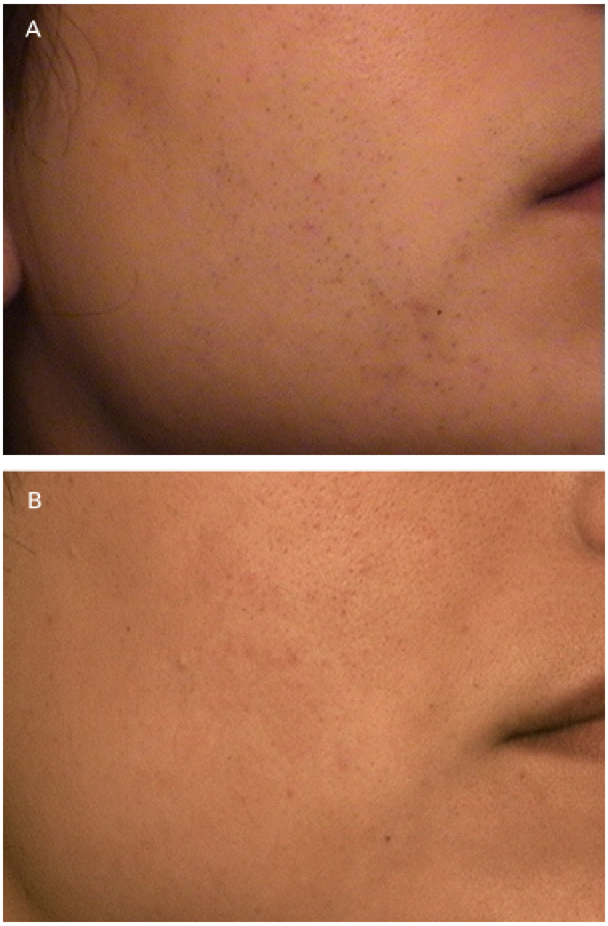

Figure 5. Facial hypertrichosis in a 26-year-old woman with skin phototype IV before (A) and 6 months after third long-pulsed 1,064-nm Nd:YAG laser treatment (B).

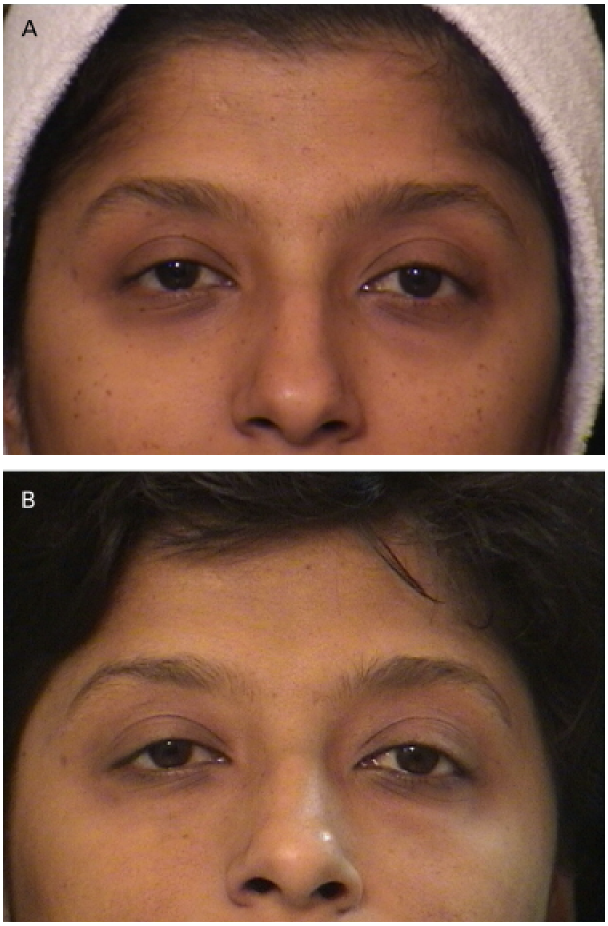

Figure 6. Facial photodamage and infraorbital hyperpigmentation in a 32-year-old woman with skin phototype V before (A) and 6 months after single-pass CO_2 laser skin resurfacing (B).

epidermal melanin absorption since its wavelength is more weakly absorbed by melanin than any other laser-assisted hair-removal modality currently available.[61–63]

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[58] or Nd:YAG[64] system with minimal untoward sequelae. Even hair induction, a relatively rare side effect of laser hair removal occurring in selected populations, body areas, and energy settings, responds well to subsequent laser treatment at higher fluences.[65]

Ablative and Nonablative Laser Skin Resurfacing

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 (Figure 6). Several reports document the long-term safety of the high-energy, pulsed and scanned carbon dioxide (CO_2) and short- and long-pulsed erbium:yttrium-aluminum-garnet (Er:YAG) lasers for the treatment of more darkly pigmented patients.[66,67]

Skin resurfacing with the CO_2 laser remains the gold standard technology for production of the most dramatic clinical and histologic improvement in severely photodamaged and scarred facial skin.[68] The latest generation of pulsed and scanned CO_2 lasers limit thermal damage by delivery of high-energy laser light with tissue dwell times shorter than the thermal relaxation time of the 30 μm of targeted water-containing tissue (approx. 1 ms). Use of the CO_2 laser for skin resurfacing yields an additional benefit of collagen tightening through heating of dermal collagen. Several CO_2 laser systems are available and can be separated into two distinct groups: pulsed and scanned. The high-energy pulsed CO_2 lasers produce single short (1-ms) pulses of very high energies. Scanned laser systems typically utilize a computerized scanning device to deliver the continuous laser energy rapidly over the skin, thus limiting the tissue dwell time in any one area.

Although techniques and applied settings vary with each patient, practitioner, and type of laser used, general principles should be followed to maximize outcome while minimizing postoperative complications. Care must be taken to avoid overlapping or stacking of laser scans or pulses to reduce the risk of tissue scar formation and subsequent scarring. Similarly, it is important to thoroughly remove partially desiccated tissue between each laser pass. If only a single pass is performed, partially desiccated tissue can remain intact to serve as a biologic wound dressing.[69] It is best to avoid resurfacing areas such as the neck and chest due to the scarcity of pilosebaceous units in these regions with resultant slow reepithelialization and potential for scarring.[70]

The short-pulsed Er:YAG laser was developed in an attempt to replicate the results of the CO_2 laser while minimizing the side effects. The emitted wavelength is absorbed more efficiently by superficial cutaneous tissues and the short erbium pulses limit thermal necrosis, resulting in shorter recovery times, reduced posttreatment erythema, and risk of dyspigmentation than CO_2 lasers.[71,72] Multiple passes with this laser are necessary to ablate to a similar depth as one pass of the CO_2 laser and, because the Er:YAG effects are photomechanical instead of photothermal (like the CO_2), intraoperative hemostasis may be difficult to achieve and collagen contraction with tissue tightening minimized.[68]

Preoperative skin preparation and meticulous postoperative care are essential for success. Effective patient education and comprehensive information about the most commonly experienced side effects, particularly postinflammatory hyperpigmentation, is crucial in the management of these patients. While transient hyperpigmentation is the most common side effect experienced after laser skin resurfacing (affecting approximately one-third of all patients), the incidence rises to 68% to 100% among patients with the darkest skin phototypes (>III).[66–74]

Of particular importance, especially those living in regions where ultraviolet radiation is most intense, is the strict avoidance of excessive sun exposure and the consistent use of full-spectrum sunblock both before and after laser treatment. Sunscreen use (SPF > 30) should be initiated at several weeks before surgery and reinstituted as soon as possible postoperatively.[75] Although they do not obviate the risk of postinflammatory hyperpigmentation, some presurgical topical treatments may enhance the eventual postoperative results. Investigators have found that, contrary to the assumptions of many clinicians, pretreatment with hydroquinone, tretinoin, or glycolic acid does not decrease the incidence of hyperpigmentation after ablative laser resurfacing in any skin phototype.[76] Pretreatment with retinoic acid, however, does appear to speed reepithelialization rates, and it can also reduce rates of melanin production after being reinstituted after the initial stage of healing is completed and the skin has regained its tolerance.[77,78] Thus, even if it does not decrease the actual incidence of posttreatment hyperpigmentation, retinoic acid may reduce its severity and duration—factors of critical importance for patients with darker skin tones.

Hypopigmentation, on the other hand, tends to be long-standing, delayed in its onset (>6 months postprocedure), and difficult to treat. Fortunately, it is observed far less frequently than is hyperpigmentation. Excimer laser and topical photochemotherapy have each shown some success in repigmenting the affected areas.[79]

Newer dermal collagen remodeling options including nonablative lasers may prove a more satisfactory compromise between efficacy and safety in patients with darker skin tones. Nonablative technologies that deliver laser, light-based, or radiofrequency energies to the skin have been the focus of a shift in recent years away from ablative techniques. A myriad of systems with "subsurfacing" capabilities has been studied, including IPL and pulsed dye, Nd:YAG, diode, and Er:glass lasers.[80–82] Typically, a series of monthly treatments are advocated in which controlled thermal injury is generated in the dermis with subsequent inflammation, cytokine up-regulation, and fibroblast proliferation.

Clinical studies have demonstrated the ability of 585 and 595-nm PDL to reduce mild facial rhytides with few side effects.[83–86] It has been hypothesized that the selective heating of dermal vessels leads to release of endothelial-derived growth factors and cytokines that up-regulate fibroblasts in treated skin, thereby resulting in neocollagenesis and rhytide reduction.

Laser systems operating in the midinfrared portion of the electromagnetic spectrum, including the 1,320-nm Nd:YAG, 1,450-nm diode, and 1,540-nm Er:glass lasers, possess optimal wavelengths for water-based nonablative skin remodeling. A cooling device provides epidermal protection concomitant with laser energy application to the dermis. These laser systems have successfully improved facial and neck rhytides, acne, and atrophic scars.[87–91]

Studies have also demonstrated rejuvenation of photodamaged skin after IPL treatment.[92–94] Improvement in skin coarseness, irregular pigmentation, pore size, and telangiectasia is typical after a series of IPL treatments (fluences 30–50 J/cm^2); however, neocollagenesis and dermal collagen remodeling with subsequent improvement in rhytides after treatment is more modest.[95]

Application of radiofrequency to skin is another nonablative technology that can be used to treat photodamaged skin. Unlike laser or light sources, which generate heat when selective targets such as oxyhemoglobin and pigment absorb photons, the radiofrequency device 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.[96,97]

One of the latest technologies introduced for laser skin resurfacing involves a 1,550-nm midinfrared 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 the residual viable epidermal and dermal cells. The process has been termed fractional photothermolysis, and it has been applied successfully to improve rhytides, atrophic scars, and dyschromia without significant risk of side effects.[44,45,98–100] This latter fact has been particularly useful in the treatment of photodamaged skin in patients with dark skin.

Summary

Dermatologic lasers have been used for more than four decades to treat a variety of cutaneous conditions, but until recently, have been limited for use in patients with pale skin. Recent developments in laser technology have provided safe and effective means to treat patients with darker skin types. Further refinements in treatment techniques will serve to optimize clinical outcomes and side effect profiles.

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COMMENTARY

I commend the authors on their exhaustive review of the literature on the treatment of skin of color with lasers. I also thank them for raising awareness for such an important topic. There is no doubt that the cosmetic use of lasers will rise along with the number of patients with skin of color presenting for treatment. The level of comfort on the part of physicians to treat skin of color must rise as well, to meet this demand. There is an inherent fear of using lasers for treating cosmetic issues in skin of color. This fear is more likely grounded in ignorance of the basic principles governing light-tissue interaction in the skin. Understanding and mastering the subtleties of laser–melanin interaction in the skin is the key to treating skin of color safely and successfully. The authors do a thorough job of discussing the technical aspects of this interaction in the context of clinical observations. Don't look now, but new technologies such as longer wavelength infrared lasers, fractional laser technologies, and the development of picosecond Q-switched lasers are on the horizon. The information presented in this article will form a good platform of knowledge for application of these devices on skin of color as they come to market.

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