Laser Treatment of Scars and Keloids

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The use of laser technology for the treatment of existing surgical scars as well as the minimization of new postoperative scars has gained considerable attention from the dermatologic and plastic surgery communities in recent years. We discuss the principles of scar treatment with both ablative and nonablative lasers, including the expanded role of fractionated technologies. We also review the evidence supporting the applicability of commonly encountered laser technologies in treating various scar types to provide busy practitioners with a resource that will facilitate the utilization of available lasers in the clinical setting. Finally, we discuss combination laser therapy, which we feel is the next frontier in laser scar treatment and prevention.

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Scarring remains an inevitable effect of the wounding process. Scars may cause notable psychosocial morbidity secondary to poor cosmesis as well as functional impairment in the case of hypertrophic scars and keloids. Techniques to minimize scar burden have been employed since ancient times, but historically the treatment and prevention of scarring has been disappointing. Exciting new research on the minimization of postoperative and traumatic scarring currently is being conducted, and the use of existing laser technologies has proven beneficial in the treatment of established scars.

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Scars can be broadly classified as hypertrophic scars, keloids, atrophic scars, and acne scars. Prior reviews of laser scar revision techniques have been organized according to the type of scar.[1] This review presents an overview of laser principles as they pertain to the treatment of scars followed by a synopsis of scar treatment organized by laser type to facilitate the busy practitioner's utilization of available resources.

PRINCIPLES OF LASER SCAR TREATMENT

Laser scar treatment is dependent on Anderson and Parrish's[2] theory of selective photothermolysis. By keeping the pulse width for a given laser shorter than the thermal relaxation time for its intended chromophore, photothermal effects are largely limited to the intended chromophore, thus reducing nonspecific or bulk heating.

Ablative laser systems such as the CO_2 and erbium:YAG (Er:YAG) lasers target water, thus promoting the vaporization of tissue. Continuous-wave ablative lasers commonly were utilized in the 1980s and 1990s; however, despite their effectiveness, these devices have fallen out of favor because of the high risk for adverse effects including scarring. To better control nonspecific heating, short-pulsed ablative lasers with high-peak power, which had the

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advantage of reliable ablation depth with decreased risk for scarring, were created, but prolonged recovery times following resurfacing procedures remained unattractive.[3] Subsequently, short-pulsed ablative energy was pixilated, thus creating deep columns of ablated tissue, also known as microthermal zones, between intervening sections of native dermis in a technique called fractional photothermolysis. Repopulation of microthermal zones by adjacent intact skin resulted in notably reduced recovery time at the expense of decreased single treatment effectiveness.[4]

Nonablative laser systems can be classified into 2 main groups: visible-light lasers (eg, pulsed dye laser [PDL] and 532-nm systems) and infrared lasers that include wavelengths designed to target the dermis and promote neocollagenesis.[3] Although they technically are not lasers, intense pulsed light (IPL) devices commonly are included in discussions of visible-light lasers because of their effective spectrum. The primary scar treatment effects of the visible-light group often are considered secondary to their vasodestructive properties, but PDL and IPL have been shown to variably initiate neocollagenesis in atrophic and photodamaged skin through unspecified mechanisms,[5,6] albeit to a lesser degree than midinfrared wavelengths.[7] Similar to ablative devices, midinfrared spectrum lasers often are fractionated, which increases the depth of collagen-stimulating thermal injury within microthermal zones, while the untreated adjacent epidermis minimizes healing time.[8]

VISIBLE LIGHT–SPECTRUM NONABLATIVE LASERS

Intense Pulsed Light

Controlled trials with objective metrics to assess the efficacy of IPL in scar treatment generally are lacking.[9,10] In a study of 109 patients with hypertrophic scars resulting from surgical incisions, trauma, acne, burns, or keloids, 92.5% of patients experienced subjective improvement in height, erythema, and hardness of their scars compared with baseline after an average of 8 IPL treatments.[11] In a split-scar study of hypertrophic scars of 6 to 8 weeks' duration from breast reduction or abdominoplasty procedures, treatment with both IPL and long-pulse PDL (1.5 milliseconds) resulted in similar subjective improvement[12]; however, without a control group, it is difficult to ascertain how much of the observed improvement in both groups resulted from maturation of these relatively young scars.

Frequency-Doubled Nd:YAG and Potassium Titanyl Phosphate Lasers (532 nm)

One controlled, split-scar study of 6 patients with pigmented hypertrophic scars reported similar improvement (36%–38%) on the Vancouver General Hospital burn scar assessment scale following treatment with the 585-nm flashlamp-pumped PDL (0.45 milliseconds) and Q-switched frequency-doubled Nd:YAG lasers, whereas the variable-pulsed mode on the same Nd:YAG laser (10 milliseconds) showed no benefit and was similar to the control group (untreated). The authors concluded that improvement of hyperpigmentation was responsible for most of the clinical effect.[13]

There is a paucity of data on the use of potassium titanyl phosphate (KTP) lasers in the treatment and prevention of scarring. Vaccaro et al[14] treated half of an established hypertrophic postthyroidectomy scar with the KTP laser and found substantial improvement in elasticity and visual appearance versus the untreated portion of the scar. In a study of 28 Asian patients with postthyroidectomy linear anterior neck incisions, Yun et al[15] prophylactically treated 20 patients using a 532-nm KTP laser for 2 treatments administered at 2-week intervals; the remaining 8 patients served as controls. Following the treatment period, the authors reported lower Vancouver scar scale and global assessment scores and higher patient satisfaction in the treatment group versus the control group.[15]

Pulsed Dye Laser

The PDL remains the workhorse for treatment of hypertrophic (Figure 1) and keloidal scars. In a 1994 report, Alster[16] used a 585-nm, flashlamp-pumped PDL to treat established hypertrophic surgical scars, reporting a 57% improvement in scar texture after 1 treatment and an 83% improvement after a second treatment. It was the first report in which the PDL laser was found to not only reduce erythema within scars but also to presumably

Figure 1. A hypertrophic scar following carpal tunnel surgery photographed after 2 pulsed dye laser treatments. Note the variable response to treatment, which was based on scar thickness. The thicker areas of this scar eventually flattened with adjuvant intralesional steroid treatment.

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redirect haphazard collagenesis as seen by reduction in scar thickness.[16] Alster and McMeekin[17] subsequently demonstrated equally impressive results in a split-face study of hypertrophic and/or erythematous acne scars using the same device. A 2011 systemic review of controlled trials found the most evidence for the 585-nm PDL in the treatment of hypertrophic scars of various etiologies.[10] Despite its more robust evidence base, the 585-nm PDL showed lower efficacy than the less often employed 595-nm PDL in the treatment of established (>6 months' duration) hypertrophic scars. The reviewers concluded there is little evidence to support lasers other than the PDL in the treatment of established hypertrophic scars.[10]

In 1999, McCraw et al[18] initially demonstrated decreased frequency of hypertrophic scar formation and improved cosmetic outcome in traumatic and surgical wounds when sequential laser treatments were performed early after wound formation, thus suggesting the 585-nm PDL can be used to prevent aberrant scar formation. Attempts to reproduce these results using a single pass of the PDL laser upon suture removal were unsuccessful.[19] McCraw et al's[18] findings were eventually confirmed by Nouri et al[20] who noted improvement of every parameter in the Vancouver scar scale after 3 monthly 585-nm PDL treatments initiated on suture removal. Furthermore, they were able to achieve similar benefits with either a 0.45- or 1.5-millisecond pulse width[20]; however, in the treatment of established hypertrophic scars, shorter pulse widths (eg, 0.45 milliseconds) are more efficacious than longer pulse widths.[21] The response to varying pulse widths in early wounds may be explained by nonspecific thermal effects on dermal collagen via signaling molecules such as heat shock proteins, whereas the dependency on short pulse widths for established hypertrophic scars may indicate that the benefits are derived primarily through the specific angiodestructive properties of this laser, which is likely an oversimplified explanation for the complex interaction between specific wavelengths of laser energy and the early wound. Nouri et al[22] also reported improvement in scar height with the 585-nm PDL that was not seen with the 595-nm PDL employed on suture removal, despite similar improvements in vascularity and pliability for these 2 wavelengths.

Parrett and Donelan[23] reviewed 6 published reports of PDL used in the treatment of hypertrophic scars from thermal burns. They concluded that the PDL leads to flattening of hypertrophic scars; improved texture and pliability; and decreased erythema, pain, and pruritus, usually after only 2 to 3 treatments. Moreover, they found no evidence of recurrent or worsening scars over the 4-week to 6-month follow-up periods in the reviewed studies.[23] However, rapid recurrence of keloidal scarring has been reported following treatment with the PDL,[24] suggesting that data from studies on hypertrophic scars cannot necessarily be extrapolated to keloids.

Diode Laser (810 nm)

The majority of research conducted using the 810-nm diode laser involves the laser-assisted skin healing (LASH) technique. Capon et al[25] found significant subjective improvement in a split abdominoplasty scar study using LASH technology at the time of skin closure; patients treated with high-dose (80–130 mJ/cm^2) laser energy demonstrated a 38.1% reduction in scar height with profilometry at 12 months following treatment (P=.027) as opposed to an insignificant difference versus control with lower-energy treatments.[25] Capon et al[26] also reported success using LASH technology in combination with silicone gel sheeting immediately following reexcision of existing hypertrophic scars. Although the mechanism of action for prophylactic laser treatment remains unknown, we agree with previously published studies that cite the modification of transforming growth factor β expression via induction of heat shock proteins (specifically heat shock protein 70) as a plausible etiology.[27]

INFRARED-SPECTRUM NONABLATIVE LASERS

Nd:YAG (1064 or 1320 nm) or Diode (1450 nm) Lasers

Infrared-spectrum nonablative lasers utilize wavelengths that selectively target water-containing tissues but provide concomitant surface cooling to prevent epidermal damage. Currently, fractionated systems are particularly popular. Treatment protocols commonly call for 3 to 4 treatments administered at 1-month intervals. Nonablative fractional laser systems have the advantage of minimal downtime with fewer side effects, especially in darker-skinned patients.

Several studies document the beneficial effects of the Nd:YAG laser in treating facial rhytides, but few address its effects on scarring. Friedman et al[28] used an optical profiler to show continued quantitative improvements in atrophic acne scarring 6 months after the fifth treatment with a Q-switched 1064-nm Nd:YAG laser. Treatments were well-tolerated aside from the development of pinpoint petechiae,[28] which previously was reported as a side effect of this device.[29] The 6-month improvement rate was 39.2%,[28] which may underestimate the potential of this laser; extended follow-up may be necessary. Treatment with the long-pulsed Nd:YAG laser also has demonstrated improvement in atrophic acne scarring in 11 of 12 patients following 5 treatments, which correlated with a statistically significant increase (P<.05) in collagen on biopsy.[30] The long-pulsed Nd:YAG laser also is well-tolerated and

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has the distinct advantage of being safe and effective for use on darker skin types.[30]

Although the majority of midinfrared lasers encountered in clinical practice today are fractionated, their unfractionated predecessors still are in use and are supported by data.[31-33] In a split-face study comparing long-pulsed 1320-nm Nd:YAG and 1450-nm diode lasers for the treatment of atrophic acne scars, Tanzi and Alster[31] demonstrated improvement in blinded appraisal of digital photographs that peaked 6 months after a series of 3 treatments with each laser. Quantitative surface topography improvement also peaked at 6 months but still remained statistically significant ($P=.008$) at the 12-month follow-up when compared to baseline. Histologically, this peak in clinical benefit coincided with the cessation of neocollagenesis after 6 months. Although both devices demonstrated improvement, the 1450-nm diode laser showed a greater response for the parameters measured at each time point.[31] These laser systems also may be considered safe for use in pigmented skin.[33,34]

FRACTIONATED NONABLATIVE LASERS

Erbium:Glass (1540 and 1550 nm) and Nd:YAG (1440 nm) Lasers

Fractionated nonablative lasers were developed in the mid-2000s to address the need for more substantial clinical improvements than what was possible using long-pulsed midinfrared systems. Alster et al[35] initially reported the efficacy of fractionated nonablative resurfacing for atrophic acne scars in 2007, with a clinical improvement rate of 51% to 75% seen in 87% (20/23) of patients after 3 monthly treatments. Chrastil et al[36] reported similar results with 23 of 29 (79%) patients experiencing greater than 50% improvement after 2 to 6 monthly treatments without persistent adverse effects, even in darker skin types. A split-face study compared the efficacy of 1540-nm fractionated laser after 3 monthly treatments versus no treatment in 10 patients with atrophic acne scars; despite the small sample size, a statistically significant ($P=.03$) improvement in blinded on-site clinical evaluation was maintained 12 weeks following the final treatment.[37]

Although most physicians still consider PDL to be the gold standard for treatment of erythematous and elevated scars, evidence suggests that nonablative fractionated resurfacing may play a role in the treatment of unsightly postsurgical scars. In a split-scar study of patients 2 months following Mohs micrographic surgery, Tierney et al[38] observed more significant improvement in overall scar appearance in the section that was treated with a fractionated 1550-nm laser compared with the section that was treated with 595-nm PDL ($P<.001$). A smaller study by Niwa et al[39] found moderate improvement when comparing baseline and posttreatment photographs of 8 patients who received fractionated 1550-nm laser treatment to their entire surgical scar. In a randomized controlled trial, Haedersdal et al[40] found significant ($P=.0007$) improvement in the texture of mature burn scars 12 weeks following the completion of 3 treatments with a 1540-nm fractionated laser versus no treatment. Despite the relatively high incidence of adverse effects, patient satisfaction remained high.[40] Finally, Waibel and Beer[41] reported drastic improvement in hypertrophic scarring with the use of a fractionated 1550-nm laser in a severely burned patient whose scars previously were refractory to intralesional steroids.

ABLATIVE LASERS (CONTINUOUS, PULSED, AND FRACTIONATED)

CO_2 Laser (10,600 nm)

CO_2 resurfacing came to the forefront of acne scar treatment with the advent of pulsed systems that were able to minimize thermal injury to uninvolved adjacent skin in the mid-1990s, thus reducing the risk for adverse effects. In the initial report of pulsed CO_2 lasers for the treatment of acne scarring, Alster and West[42] demonstrated an 81.4% average clinical improvement in acne scars after only 1 treatment but noted hyperpigmentation lasting an average of 3 months in 36% of patients. In 2008, Chapas et al[43] described the use of a fractionated CO_2 resurfacing technique for the treatment of acne scars. The mean level of improvement after 2 to 3 monthly treatments (66.8%) was felt to be slightly less than that achieved using a single pass with the pulsed CO_2 predecessor, but the side-effect profile and healing times were more desirable than those associated with continuous or pulsed CO_2 lasers.[43] In 2012, Ong and Bashir[44] reviewed all 26 published reports of fractional ablative and nonablative acne scar resurfacing and found that although nonablative devices had a better side-effect profile, there was more potential for improvement with ablative (26%–83%) versus nonablative (26%–50%) fractionated lasers. Although the safety of both ablative and nonablative fractional devices in ethnic skin has been documented,[45] our experience has suggested that there is increased risk for temporary hyperpigmentation when using ablative wavelengths at more aggressive settings.

Although the vast majority of published reports for CO_2 laser systems involve the treatment of acne scars, there also is evidence to suggest utility in other forms of scarring (Figure 2). In a study of 15 patients with 22 nonatrophic acne scars, 3 treatments with the fractionated CO_2 laser led to a 38% mean reduction in scar volume and a 35.6% mean reduction in maximum scar depth at

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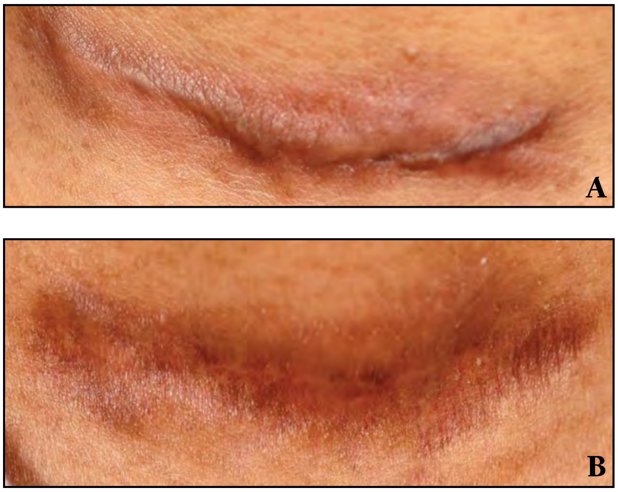

Figure 2. A postthyroidectomy scar with malapproximation of the wound edges leading to a poor cosmetic outcome (A). Induration and pliability responded favorably to 3 treatments with a fractionated CO_2 laser (B), while the resulting hyperpigmentation responded to treatment with an alexandrite Q-switched laser (not pictured).

6 months. This degree of dermal rejuvenation was sufficient to create perceived improvements in texture, atrophy, and overall scar appearance by both investigators and patients at 6 months posttreatment.[46] Lee et al[47] reported subjective improvement in all 27 patients with striae distensae treated with a single pass of a fractionated CO_2 laser, noting that nonablative fractional systems approved for this indication usually require multiple treatments. However, when 3 treatments with the nonablative 1550-nm fractionated laser were compared head-to-head with 3 fractionated CO_2 treatments in a split-scar study for striae distensae, no significant difference between the 2 wavelengths was found.[48]

CO_2 laser resurfacing also has come to the forefront of hypertrophic and/or burn scar treatment. Although continuous-wave and pulsed devices were often fraught with unpredictability and unacceptable downtime, a 2006 Iranian study of more than 300 patients receiving 10 weekly low-level laser treatments for burn scars using a scanning CO_2 system showed significant ($P<.001$) improvement to resolution for hypertrophic scars of 1 to 6 months' duration, whereas there was only moderate to limited effect in more mature scars.[49] More recently, several case reports have highlighted the potential of fractionated CO_2 in this patient population. Waibel and Beer[50] demonstrated drastic clinical improvement in a long-standing facial burn scar with a single treatment of a fractionated CO_2 laser, citing the potential role of heat shock proteins in skin remodeling. Cho et al[51] demonstrated safety and efficacy of the fractionated CO_2 laser in the treatment of thermal burn scars in an Asian patient. Despite the improved safety profile of newer fractionated CO_2 lasers, it is still possible to induce new hypertrophic scarring with these devices, and as such caution must be exercised.[52]

Ablative laser resurfacing also is being used in the prevention of undesirable scarring postoperatively and following nonburn trauma. Early intervention with fractionated CO_2 2 to 3 weeks postthyroidectomy has been suggested to improve the clinical appearance of hypertrophic scarring in at least 1 uncontrolled trial.[53] Jared Christophel et al[54] conducted a split-scar study comparing fractionated CO_2 to diamond fraise dermabrasion in postsurgical scars and found similar efficacy between the modalities but increased safety with CO_2. Treatment of the wound edge intraoperatively with either pulsed CO_2[55] or fractionated CO_2[56] has proven to benefit postoperative scar appearance.

Er:YAG Laser (2940 nm)

The water absorption coefficient for the Er:YAG laser is 16 times that of the CO_2 laser, which leads to less penetration depth per laser pass, less thermal injury, poor hemostasis, and reduced efficacy for facial resurfacing with short-pulsed Er:YAG.[3,57] The limited penetration of Er:YAG has been overcome by newer devices that utilize increased pulse widths, thus allowing deeper thermal damage and increased effectiveness in the treatment of atrophic acne scarring.[58,59] Although shallow boxcar and ice pick–type scars respond to any type of Er:YAG laser, longer pulse durations are required to stimulate the collagenesis that improves rolling and deep boxcar scars.[60] Not surprisingly, the side-effect profile of the long-pulse Er:YAG laser is similar to pulsed CO_2 resurfacing for acne scars.[61]

There is 1 randomized larger study assessing the utility of Er:YAG in the treatment of traumatic or surgical hypertrophic scars. The authors concluded that both the low-energy, short-pulsed Er:YAG laser and standard flashlamp PDL were superior to intralesional steroid injection, but they did not appear to find any significant difference between the 2 lasers.[62] A large potential for bias has been noted in this study.[10]

COMBINATION THERAPY

CO_2 Laser and PDL

Some investigators have postulated that increased benefits can be achieved if combination laser therapy is utilized in the treatment of postsurgical or traumatic scars (Figure 3); to our knowledge, however, few studies exist. Pulsed dye laser therapy remains an excellent option for the erythematous component of established scars, but as previously mentioned, it also can improve

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Figure 3. Complex traumatic scars respond best to a multiple laser approach. This road rash scar following a motorcycle accident responded well to treatment with a Q-switched laser to improve resultant hyperpigmentation/traumatic tattoos, a pulsed dye laser to improve erythema, and a fractionated ablative laser to improve surface texture.

other variables such as scar texture and height. Alster et al[63] compared the results of a pulsed CO_2 laser with and without simultaneous PDL treatment and found the combination therapy to be superior in the resurfacing of nonerythematous hypertrophic scars. Similar to Manuskiatti et al[64] who used multiple wavelengths to target specific chromophores in a single laser resurfacing session to repair photodamaged skin, we have found that the treatment and/or prevention of hypertrophic and otherwise unsightly postsurgical and traumatic scars can be improved by a multiple modality approach. As such, we currently are conducting a randomized controlled study to compare the effects of fractionated CO_2 laser therapy, PDL therapy, and a combined therapy using both devices in minimizing postsurgical scars (P.B. and C.H., unpublished data, 2012).

Intralesional Therapy

Intralesional steroid injections once were considered the standard therapy to which all scar reduction modalities were compared. Several studies that assess the efficacy of lasers for scar reduction include comparisons to intralesional steroids. Manuskiatti and Fitzpatrick[65] reported similarities in clinical improvement when comparing 585-nm PDL monotherapy, 5-fluorouracil monotherapy, intralesional steroid monotherapy, and intralesional steroid in combination with 5-fluorouracil; however, the authors noted more unwanted side effects in the corticosteroid treatment groups. There are fewer trials that assess combination laser and intralesional injection therapies. Asilian et al[66] found the combination of an intralesional steroid, 5-fluorouracil, and 585-nm PDL to be more effective in treating keloids and hypertrophic scars than the intralesional steroid alone or in combination with 5-fluorouracil only.

FUTURE DIRECTIONS

Scar prevention and treatment have come to the forefront of dermatology within the last few years. Several recent review articles that address treatment modalities and the pathogenesis of wound healing hopefully will encourage continued research in this intriguing field.[1,9,67,68] Combination therapies that warrant further investigation with prospective controlled studies include dermal fillers combined with fractionated CO_2 resurfacing for the treatment of acne scars, botulinum toxin combined with early fractionated CO_2 with and without PDL resurfacing, and laser resurfacing combined with a variety of wound dressings.

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