An Overview of Lasers for the Treatment of Scars

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Nearly every person will have at least one scar throughout his/her lifetime. Ablative lasers vaporize the epidermis and upper dermis, which causes collagen denaturation and contraction. They have the highest improvement rate but also the most complications and side effects. Nonablative lasers are used for more delicate procedures. The epidermis remains intact and injury is localized to the papillary and superficial portion of the reticular dermis. The degree of clinical effect is milder than ablative or fractional laser treatment, but the recovery time is much shorter than with ablative lasers. Fractional laser treatment with the 1550-nm erbium fiber laser was developed as a bridge between the ablative and nonablative lasers. Fractional photothermolysis creates many microscopic areas of thermal necrosis within the skin called microscopic treatment zones and has established itself as an alternative treatment to the conventional ablative and nonablative laser therapy for the treatment of scars. We review current laser technology for the treatment of scars. *Cosmet Dermatol.* 2011;24:314-320.

Scars occur as a normal result of wound healing and nearly everyone will have at least one scar throughout his/her lifetime.[1] Multiple therapeutic modalities, including chemical peels, dermabrasion, dermasanding, surgical scar revision, electrosurgical planing, dermaplaning, dermal/subdermal fillers, silicone injection, autologous fat transplantation, pressure therapy, and radiation, have been explored to treat scars.[2-5] Twenty years of laser research and exploration have given cosmetic surgeons the ability to diminish scars in both appearance and symptoms. We review current laser technology for the treatment of scars as well as the limitations, side effects, and complications of laser therapy.

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The authors report no conflicts of interest in relation to this article.
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SCAR CLASSIFICATIONS

The proper classification of scars is necessary to determine the type of laser that should be used for treatment.

Hypertrophic Scars and Keloids

Hypertrophic scars and keloids occur when wound healing deviates from its highly regulated process. For largely unknown reasons, an imbalance occurs between the anabolic and catabolic phases of the healing process, with the end result being more collagen production than degradation.[6-8] Factors that are thought to be dysregulated leading to greater-than-normal collagen deposition include increased levels of growth factors (eg, transforming growth factor [TGF] $\beta 1$[9-11]); increased platelet-derived growth factor[12]; increased histamine, carboxypeptidase A, prostaglandin D_2, and tryptase[13-15]; and decreased matrix metalloproteinases and IL-1α.[16,17]

A keloid or hypertrophic scar can be distinguished both clinically and histologically.[18] Clinically, keloids

extend beyond the margins of the original wound, whereas hypertrophic scars remain within its borders. Keloids are deep red or purple in color, whereas hypertrophic scars can range from white to dark red. Histologically, keloids are composed of disorganized, thick, hyalinized collagen with a prominent mucoid matrix, and hypertrophic scars are characterized by fewer and more organized collagen fibers with a scanty mucoid matrix.

Hypertrophic scars and keloids are difficult to prevent and probably even more difficult to treat. Medical therapies for hypertrophic scars and keloids include intralesional corticosteroids, intralesional interferon, intralesional 5-fluorouracil, doxorubicin hydrochloride, bleomycin, verapamil, retinoic acid, imiquimod cream 5%, tacrolimus, tamoxifen citrate, botulinum toxin, TGF-β3, and recombinant human IL-10. Despite the numerous therapeutic approaches, their side effects often outnumber and outweigh the benefits. Surgical treatments that have been explored with variable recurrence rates include cryosurgery, excision, and laser therapy. The clinical outcomes using these modalities have resulted in variable recurrence rates.[19-21]

Atrophic Scars

Atrophic scars are caused by dermal depressions due to collagen destruction from an inflammatory skin disease such as cystic acne or varicella. Makeup used to conceal these scars may further accentuate them.

Acne Scars

Although acne scars most commonly present as atrophic scars, they are seldom hypertrophic or keloidal. Atrophic scars can further be classified as either superficial or deep dermal scars. The former type consists of primarily superficial macular scars, which can be treated with retinoids and sunscreen. The latter type involves the dermis and leads to inflammation of the lower structures as well as atrophy of the overlying skin. Deep atrophic scars can be further classified into 3 types: ice pick, rolling, or boxcar scars. Ice pick scars are narrow (<2 mm), deep pitted scars with steep edges. They are wider at the top and taper downward. Rolling scars are shallower and wider (4–5 mm), producing an undulating appearance to the cutaneous surface caused by the abnormal fibrous attachment of the dermis to the subcutaneous tissue. Boxcar scars can be shallow, deep, round, or oval depressions on the skin surface with sharp margins. Unlike ice pick scars, they do not taper.[22]

Striae Cutis Distensae

Striae cutis distensae are commonly referred to as stretch marks. They form in areas subjected to continuous and progressive stretching. Increased stress is placed on the connective tissue, for example, because of the increased size of the abdomen and breasts of pregnant women. Striae cutis distensae also can be found on the shoulders of body builders, in adolescents undergoing growth spurts, and in individuals who are overweight. Although not fully understood, skin distension leading to excessive mast cell degranulation followed by lysis of collagen and elastin has been implicated in the pathogenesis of striae.[23] Other factors thought to play a role are prolonged use of oral or topical corticosteroids, Cushing syndrome (increased adrenocortical activity), and estrogen.[24]

The striae initially present as flattened thinner skin with a pink hue. They gradually enlarge in size and become reddish purple in appearance (striae rubra) because of dermal inflammation and dilated capillaries. The surface of striae may be finely wrinkled. Upon maturation of the lesions, striae become hypopigmented and fibrotic.

LASERS IN THE TREATMENT OF SCARS

Many theories have been suggested regarding the mechanism of action by which laser irradiation improves the appearance of scars. Most of the hypotheses are based on the principle of selective photothermolysis.[25] Vascular proliferation is thought to play a key role in the development of keloids and hypertrophic scars, and lasers are used in the hope of exploiting this concept. The light energy emitted from a vascular laser is absorbed by hemoglobin, generating heat and leading to coagulation necrosis,[26-30] which in turn causes decreased perfusion and hypoxia inducing neocollagenesis, dissociation of disulfide bonds from collagen fibers, heat resulting in collagen realignment, histamine release, and release of fibroblast activity modulators.[27-29,31-34]

Certain molecular effects of lasers on keloids have been studied.[35] Notably, the 585-nm pulsed dye laser (PDL) decreases fibroblast proliferation and collagen type III deposition. Apoptosis is induced and extracellular signal-regulated kinase and p38 mitogen-activated protein kinase activity are upregulated. Downregulation of TGF-β1 expression has been demonstrated. An increase in matrix metalloproteinase (collagenase-3) activity also has been reported.[9] The superpulsed CO_2 laser, on the other hand, stimulates the release of basic fibroblast growth factor and inhibits TGF-β1 release.[36] Laser-induced hypoxia alters collagen synthesis by fibroblasts and degradation through metalloproteinase release.[37] The lasers used in the treatment of scars can be broadly classified into ablative and nonablative lasers.

Ablative Lasers

Ablative lasers ablate or vaporize the epidermis and upper dermis, which causes collagen denaturation and

contraction. During the healing period, reepithelialization from hair follicles and other adnexal tissue occurs along with a band of collagen remodeling. The ablative lasers commonly used in dermatologic practice of scar treatment are CO_2 lasers, erbium:YAG (Er:YAG) lasers, and a combination of both.

CO_2 Lasers—The CO_2 laser is useful for improving atrophic scars caused by acne, surgery, and trauma. It emits an infrared beam at a 10,600-nm wavelength and targets both intracellular and extracellular water. The tissue containing the water absorbs the light energy, resulting in skin vaporization and coagulative necrosis in the dermis.

For the purpose of cutaneous resurfacing, different high-energy, pulsed, and scanned CO_2 lasers are currently available.[38] Despite the same basic principles of selective photothermolysis, there are notable differences between the lasers in tissue dwell time, energy output, and laser beam profile that result in different clinical and histologic tissue effects.[39]

The use of CO_2 lasers is limited to the face, which has abundant cutaneous appendages.[39] These cutaneous appendages provide the epithelial cells that migrate upward to form new epidermis following injury with the laser. The overall success of cutaneous resurfacing with these lasers is directly proportional to the number of skin appendages per square centimeter of skin, provided that the proper technique is used. The more common side effects encountered by patients are pain, edema, pruritus, and tightness, which occur in nearly all patients and generally are transient. The complications associated with CO_2 laser resurfacing range from mild (eg, milia formation, perioral dermatitis, acne/rosacea exacerbation, contact dermatitis, postinflammatory hyperpigmentation) to moderate (eg, localized viral, bacterial, and fungal infection; delayed hypopigmentation; persistent erythema) to severe (eg, hypertrophic scarring, disseminated infection, ectropion formation).[39]

Erbium:YAG Lasers—High-energy pulsed or scanned CO_2 laser skin resurfacing is associated with an extended reepithelialization period consisting of 7 to 10 days with prolonged erythema and the potential for permanent hypopigmentation. The demand for less aggressive therapeutic options for skin rejuvenation when compared with the CO_2 laser led to the development of the Er:YAG laser. The pulsed Er:YAG lasers emit at the 2940-nm wavelength, which has 10 times more affinity for water-containing tissues, hence achieving a much finer level of tissue ablation, reduced thermal injury, and minimal erythema compared with its CO_2 counterpart. The clinical and histologic improvements obtained with the Er:YAG lasers are milder than CO_2 lasers; however, the short-pulsed Er:YAG laser system is an excellent ablative tool for cutaneous resurfacing in cases of mildly atrophic scars, offering comparable clinical effects with shorter postoperative recovery time. Reepithelization after resurfacing typically takes 4 to 7 days. Additionally, in darker-skinned patients, the Er:YAG laser is the preferred ablative laser treatment.[40] Despite the advantages offered by Er:YAG lasers, poor intraoperative hemostasis and less-than-impressive clinical improvement (reduced tissue tightening) compared with traditional high-energy pulsed or scanned CO_2 laser resurfacing reserve its use for sculpting of individual scar edges and treatment of mild acne scars. Complications associated with Er:YAG lasers are similar to CO_2 lasers, namely infections, hypertrophic scarring, ectropion formation, and pigmentary alteration, but these complications generally are less severe with Er:YAG lasers. In an attempt to overcome the limitations of the short-pulsed Er:YAG laser, modulated (short- and long-pulsed) Er:YAG systems were introduced to facilitate deeper ablation of tissue, improve hemostasis, and increase collagen remodeling.

Combined Er:YAG/CO_2 Laser—The combined Er:YAG/CO_2 laser has the ability to simultaneously deliver the ablation of the erbium wavelength (2940 nm) and a deeper penetrating subablative thermal pulse of CO_2,[41,42] which helps achieve notable clinical improvement with less associated morbidity in treating atrophic facial scars. The dual-mode system generates just enough thermal injury to stimulate neocollagenesis while, at the same time, vaporizing just enough tissue to avoid excessive thermal necrosis. The side-effect profile observed with this system is limited to transient hyperpigmentation and acne flare-ups. The modulated and dual-mode Er:YAG lasers have the advantage of better hemostasis while achieving ablation of tissue to a greater depth than the conventional Er:YAG lasers.[43]

Nonablative Lasers

The epidermis remains intact with nonablative laser treatments with localized thermal injury to the papillary and superficial portion of the reticular dermis. Nonablative lasers are used for more delicate procedures such as under the eyes, lines, and wrinkles, as well as for superficial acne scars. Although the degree of clinical effect is milder than with ablative or fractional laser treatment, the recovery time is much shorter than ablative lasers. The nonablative lasers used in treatment of scars include the PDL, Nd:YAG laser, and Q-switched Nd:YAG laser.

Pulsed Dye Laser (585 nm)—The flashlamp-pumped PDL was the first laser specifically designed for the treatment of vascular lesions. Its design was based on the theory of selective photothermolysis that allows for its successful use in the treatment of hypertrophic scars and keloids, targeting the microvasculature of the scar without damaging the surrounding normal tissue.[30] Selective targeting of desired

tissue without injuring the surrounding skin is achieved by using a pulse duration (the time of exposure to light) shorter than the chromophore's thermal relaxation time (the time required for the targeted lesion to cool to half of the peak temperature). It has been suggested that the PDL causes collagen remodeling through cytokine stimulation, disulfide bond disruption through tissue heating, laser-induced tissue hypoxia, and decreased TGF-β and extracellular matrix expression.[9,44]

Currently used wavelengths of the PDL include 585, 595, and 600 nm. The longer wavelength was thought to allow deeper penetration of the laser light; however, Pikkula et al[45] have demonstrated that when using the same fluence, the 585-nm PDL actually penetrates deeper than the 595-nm PDL. Albeit, fluences of 10 J/cm^2 and higher were used.[45]

In a study conducted by Alster and colleagues,[46] skin surface texture analysis and clinical assessments demonstrated that the laser-irradiated scars approximated normal skin characteristics. In 1996 McDaniel and colleagues[47] demonstrated the usefulness of the 585-nm PDL in improving the appearance of striae, and in 2003 Nouri and colleagues[48] reported improvement in the quality and appearance of surgical scars when the PDL was used as early as the day of suture removal. Multiple studies have shown dramatic improvement in scar erythema, pliability, texture, and thickness with the use of the PDL, especially in hypertrophic scars and keloids.[49-52] The most common adverse reactions encountered with the PDL are purpura and transient hyperpigmentation or hypopigmentation. The former may last several days, whereas the latter may resolve over a few weeks.[52]

Nd:YAG Laser—The continuous-wave Nd:YAG laser (1064 nm) selectively inhibits collagen production by a direct photobiologic effect and creates tissue infarction, which results in charring and sloughing of the treated area. The 1320-nm Nd:YAG combines epidermal surface cooling with a deeply penetrating wavelength that selectively targets water-containing tissue, thereby creating selective thermal injury in the dermis without damage to the epidermis. Histologic evaluation and skin surface texture measurements have demonstrated an improvement of scars by 40% to 45%.[53] A study conducted by Tanzi and Alster[53] using a split-face design compared the efficacy of the 1320-nm Nd:YAG and the 1450-nm diode laser in the treatment of 20 patients with mild to moderate atrophic facial scarring. Use of the 1450-nm diode laser was noted to result in longer posttreatment erythema and edema.[53] The type of scarring rather than its extent may be the best predictor of response rate to laser therapy; for example, ice pick scars are not likely to respond. Side effects and complications of treatment with Nd:YAG lasers are similar to the PDL and other nonablative lasers.

Q-switched Nd:YAG Laser—The Q-switched Nd:YAG laser is a nonablative laser developed to create short pulses (5–100 nanoseconds). The 532-nm Q-switched Nd:YAG laser and the 585-nm PDL offer comparable and favorable results in the treatment of pigmented hypertrophic scars. The 532-nm Q-switched Nd:YAG laser may be preferred for scars with dark colors.[54] In a 6-month follow-up study conducted in 2004, it was demonstrated that after 5 treatments with the Q-switched Nd:YAG laser, substantial qualitative and quantitative improvements in facial acne scars occurred.[55] The histology after treatment showed mild dermal fibrosis and reduced solar elastosis with thickening of the papillary dermal collagen.[39,56-59] The Q-switched Nd:YAG laser offers patients the advantages of nonablative lasers with regard to its minimal recovery time and minimal risk for infectious and pigmentary complications.

FRACTIONAL PHOTOTHERMOLYSIS

Fractional laser treatment was developed as a bridge between the ablative and nonablative lasers used to treat acne scars, surgical scars, photodamaged skin, fine wrinkles, and melasma. Fractional photothermolysis employs an array of small laser beams that target water as its chromophore.[60] It creates many microscopic areas of thermal necrosis within the skin called microscopic treatment zones.[61]

Fractional lasers can be divided into ablative and nonablative categories. Ablative fractional laser devices include the Er:YAG 2940-nm, yttrium scandium gallium gamet 2790-nm, and CO_2 10,600-nm lasers,[60] whereas the nonablative fractional devices are composed of the erbium fiber 1410-nm, the Nd:YAG 1440-nm, the intense pulsed light–powered 1540-nm, and the erbium fiber 1550-nm lasers.[60] The microscopic treatment zones are surrounded by normal intervening skin that rapidly heals the injured tissue. The laser induces a dense array of microscopic columnar thermal zones of tissue injury that do not perforate or impair the function of the epidermis, producing minimal side effects. Fractional photothermolysis generates a safe yet effective treatment of acneform scarring, atrophic scarring, surgical scars, thermal burns, and hypopigmentation.[62-69] Fractional photothermolysis has established itself as an alternative treatment modality to conventional ablative and nonablative laser therapy.[66,70,71]

FRACTIONAL RADIOFREQUENCY DEVICE

Although not a laser, the latest approach in the treatment of acne and atrophic scarring includes the use of

a nonablative radiofrequency device. The radiofrequency technology produces an electric current that generates heat through resistance in the dermis and subcutaneous tissue, which further stimulates neocollagenesis and collagen remodeling. More investigations are needed to determine its exact role in the treatment of scars.

CONCLUSION

Nearly every person will have at least one scar throughout his/her lifetime. As dermatologic surgeons, we create scars on our patients every day and we owe it to them to continually strive for better results. Nearly 20 years of laser research has led to technology that allows us to improve patients' scars; however, we still have a long way to go. The CO_2 laser has demonstrated clinical efficacy in improving atrophic scars caused by acne, surgery, and trauma. The Er:YAG laser is used for similar indications but is associated with less efficacy, shorter recovery time, and fewer side effects/complications than the CO_2 laser. The flashlamp-pumped PDL has shown clinical efficacy in the treatment of hypertrophic scars and keloids, targeting the microvasculature of the scar. The continuous-wave Nd:YAG laser (1064 nm) selectively inhibits collagen production. It combines epidermal surface cooling with a deeply penetrating wavelength, creating selective thermal injury in the dermis without damage to the epidermis. The Q-switched Nd:YAG laser is a nonablative laser developed to create short pulses (5–100 nanoseconds). The 532-nm Q-switched Nd:YAG laser and the 585-nm PDL offer comparable results in the treatment of pigmented hypertrophic scars. Fractional laser treatment with the 1550-nm erbium fiber laser has been developed as a bridge between the ablative and nonablative lasers used to treat scars. It demonstrates more clinical efficacy than nonablative lasers but is not associated with as much recovery time as fully ablative lasers. A considerable amount of research still needs to occur so that we can develop better techniques with the hope that one day patients will not have to continue living with the reminder of a painful incident, be it a trauma, pathophysiology, or surgery.

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