Review Article

Fractionated CO_2 Laser Resurfacing: Our Experience With More Than 2000 Treatments

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Fractionated carbon dioxide (CO_2) laser resurfacing combines the concept of fractional photothermolysis with an ablative 10600-nm wavelength. This technology allows for the effective treatment of rhytides, photodamage, and scars, with shorter recovery periods and a significantly reduced side effect profile as compared to traditional CO_2 laser resurfacing. In this article, the authors review the concept of fractional photothermolysis, the expanding array of indications for use of fractionated CO_2 lasers, and their preferred treatment technique. (*Aesthetic Surg J 2009;29:317–322.*)

For nearly 15 years, the carbon dioxide (CO_2) laser has been the gold standard treatment for skin resurfacing. Despite its superiority in the treatment of rhytides,[1-3] photodamage,[4,5] and acne scars,[6,7] the CO_2 laser has fallen out of favor in recent years because of the lengthy recovery period required after treatment and the high reported incidence of serious side effects. The two most notable and well documented side effects of CO_2 laser resurfacing are scarring and delayed onset hypopigmentation.

SIDE EFFECTS OF CARBON DIOXIDE LASER RESURFACING

Tissue ablation and thermal coagulation of the dermis are thought to drive the robust dermal remodeling that translates into clinical improvement following CO_2 laser resurfacing. However, excessive ablation and thermal damage is responsible for the scarring that can occur after CO_2 laser treatment. More aggressive treatments with higher energies and an increased number of passes can provide more dramatic clinical results; however, this comes at the expense of an increased risk for scarring. For these reasons, the skill and expertise of the practitioner is key in avoiding overly aggressive treatments. The development of high-energy pulsed CO_2 lasers and the flash scanner CO_2 laser system reduced the incidence of scarring compared to the original continuous wave CO_2 laser, but scarring continues to remain a concern with these lasers.

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Hypopigmentation of CO_2 laser–treated skin is a late-appearing but permanent side effect reported to occur in up to 57% of patients.[8,9] The observed hypopigmentation may be divided into cases of true hypopigmentation, defined as decreased melanogenesis, and pseudohypopigmentation, defined as relative lightening of treated skin compared to adjacent untreated bronzed and sun-damaged skin.[2,9,10] Whether true or pseudo, hypopigmentation creates noticeable lines of contrasting colors along the border of treated and untreated skin. This undesirable effect draws attention to the treated area and is cosmetically disturbing to patients.

DEVELOPMENT OF ABLATIVE FRACTIONAL RESURFACING

The avoidance of scarring, hypopigmentation, and lengthy recovery periods is a major factor behind the development and rising popularity of newer nonablative lasers. These nonablative lasers generally target the dermis and attempt to stimulate dermal remodeling while avoiding epidermal injury and prolonged healing times. Although very safe, these devices are unable to generate significant dermal coagulation. As a result, their clinical results are modest at best compared to those of CO_2 laser resurfacing.

The concept of fractional photothermolysis (FP)[11] revolutionized laser surgery by enabling the delivery of dermal coagulative injury without confluent epidermal damage. Originally designed to emit a shorter nonablative wavelength, FP systems deliver microthermal zones (MTZ), which are columns of controlled thermal injury to the skin, in an evenly spaced pattern resembling pixels in a digital image. MTZ are surrounded by healthy, untreated skin, which allows for rapid reepithelialization via the migration of cells from immediately adjacent epidermis and follicular units. Repair of dermal injury is also accelerated because of the proximity of healthy fibroblasts, which are able to upregulate collagen production, migrate into the treated dermis, and facilitate collagen remodeling. Efforts to improve upon nonablative FP systems have led to the development of a new generation of fractional ablative CO_2 lasers.

Ablative fractional resurfacing (AFR) was created by combining the 10600-nm wavelength of the CO_2 laser with an FP system. AFR achieves controlled tissue vaporization and thermally-induced dermal coagulation extending to far greater depths than those of both traditional CO_2 lasers and newer nonablative devices. AFR thereby produces greater tissue contraction, collagen production, and dermal remodeling than is seen with nonablative FP devices. The net effect is the ability to obtain clinical efficacy approximating that of traditional CO_2 laser ablation while enjoying a much more favorable side effect profile.

The advantages of AFR over traditional CO_2 laser resurfacing are numerous. Most notably, with proper technique, there is a very low risk of scarring or hypopigmentation. We have used AFR in our office to perform more than 2000 procedures in the past four years, with an overwhelmingly positive response from patients. To date, we have not experienced a single case of scarring or hypopigmentation. While idiosyncratic responses can lead to complications, the few reported cases of AFR treatment–related scarring in the literature[12,13] are likely attributable to improper treatment technique or overly aggressive energy or density settings (see discussion on treatment technique below).

Beyond avoiding the serious long-term complications seen with CO_2 laser resurfacing, AFR allows for much quicker recovery and fewer short-term side effects. Following full-face resurfacing with AFR, complete reepithelialization is generally seen in three to six days. This is in stark contrast to the two to three weeks of recovery following full-face resurfacing with traditional CO_2 laser systems. Rapid reepithelialization after AFR treatment results in very few infections, which are further reduced with the recommended use of prophylactic antiviral and antibiotic medications. Faster reepithelialization also results in patients requiring fewer days of occlusive ointment application. This greatly reduces the rate of acneiform eruptions, which are seen in up to 83% of patients treated with traditional CO_2 lasers.[10] Erythema, an expected side effect after treatment, also resolves much more quickly after AFR compared to nonfractionated CO_2 laser treatments.

TYPES OF ABLATIVE FRACTIONAL RESURFACING DEVICES

The impressive clinical results and favorable side effect profile of AFR has generated a new market for ablative fractional devices. There are currently a number of laser devices available that incorporate AFR technology, but a detailed evaluation of each of these devices is beyond the scope of this article. It should be noted, however, that the major differences between devices pertain to the depth of ablation and coagulation and to variations in treatment handpieces. These handpieces determine the manner in which the treatments are performed. The authors' experience is primarily with the Fraxel re:pair laser (Solta Medical, Hayward, CA), which has a continuous motion (rolling) optical tracking system. The handpiece evenly delivers MTZ with a 135-μm diameter by adjusting its scanning system according to the operator's hand speed, allowing for consistent and efficient treatments. Other AFR devices equipped with "stamping" handpieces require more time to treat and considerable effort to perform an even treatment without undesired overlap. This is particularly evident on concavities and convexities of the face that are difficult to treat, such as the nose. The depth of ablation and coagulation of the laser is also important, as it directly correlates with treatment efficacy.[8,14] The Fraxel re:pair laser has been shown histologically to deliver MTZ that extend to a depth of 1.6 mm into the dermis (at 70 mJ). Manufacturers of other fractionated CO_2 lasers have made claims that their devices deliver ablation and dermal coagulation penetrating to depths of 50 μm to 2000 μm.

TREATMENT INDICATIONS AND METHODS

Similar to traditional CO_2 laser resurfacing, the most common indications for AFR treatment are facial rhytides, sun-damaged skin, and acne scarring. Considerable improvement and patient satisfaction is usually attained with one or two treatments. Rarely, with deep acne scars, additional treatments are performed with resultant incremental cosmetic improvements. The beauty of AFR is that one can safely treat the entire face, the neck and chest, individual cosmetic units, or even individual scars without a concern for pigmentary alteration. As with any laser treatment, all AFR treatments should begin first with a consultation in which expectations are set. The patient should be fully informed about necessary pretreatment prophylaxis, anesthesia, post-treatment skin care, and follow-up visits.

In our practice, full-face AFR treatments were performed in an outpatient office setting. Some physicians prefer to perform the procedure with intravenous sedation administered by an anesthesiologist in the outpatient setting or under general anesthesia administered in an operating room. Our patients began a seven-day course of prophylactic antibiotic and antiviral medications one day before the procedure. They arrived one hour before their scheduled treatment, at which time they received preoperative medications (an intramuscular dose of ketorolac [60 mg], an oral dose of diazepam [5–10 mg], and an oral dose of acetaminophen/oxycodone [5/325 mg]). A topical anesthetic (7% lidocaine/7% tetracaine) was applied to the treatment areas and remained on the skin for 60 minutes. Fifteen minutes before the procedure, supraorbital, infraorbital, and mental nerve blocks were administered using a

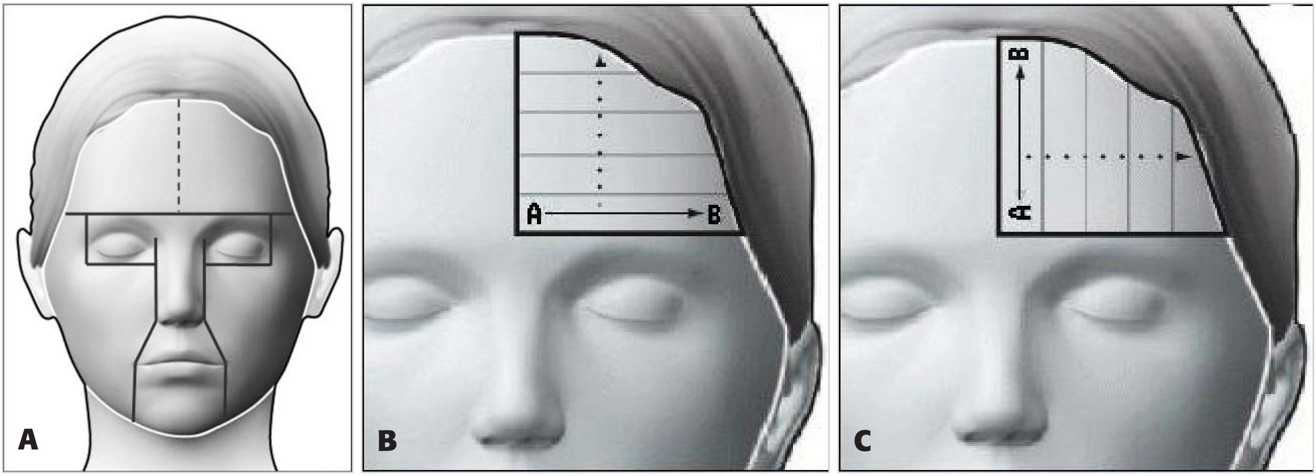

Figure 1. Treatment technique. **A**, Treatment is performed by sequentially treating cosmetic units. **B**, Within each cosmetic unit, nonoverlapping rows are delivered in one direction. **C**, Subsequent passes over the same cosmetic unit are delivered perpendicularly to the previous pass. (Modified with permission of Solta Medical. ©2006 Reliant Technologies LLC.)

total of 12.0 mL of 1% lidocaine with 1:100,000 epinephrine. Immediately before the procedure, the patient was positioned comfortably on their back and the topical anesthetic was gently removed from the skin. Topical anesthetic eye drops (tetracaine 0.5% ophthalmic solution) were administered, followed by the placement of protective metal eye shields that were coated with antibiotic ophthalmic ointment. Patients usually tolerated the treatment well when given the anesthesia described above; however, some patients required additional local anesthesia, especially in the lateral cheeks, which are not affected by the infraorbital nerve blocks.

The treatment was performed by sequentially treating the cosmetic units—cheeks, nose, lips, chin, temples, forehead, and eyelids—with the desired number of passes at the desired energy fluence. Forced cold air was administered with the Zimmer Cryo6 cooling system (Zimmer MedizinSystems, Irvine, CA) to further lessen patient discomfort. Care was taken to complete each pass of the cosmetic unit with nonoverlapping rows in one direction. Each additional pass was delivered perpendicular to the previous pass, as illustrated in Figure 1. Adjacent rows should not be made in an up-and-down fashion because this can lead to bulk heating of the treated skin. Bulk heating refers to accumulation of heat in the tissue as a result of repetitive or overlapping passes with the laser. Excessive heat accumulation may lead to broad zones of thermal damage and subsequent scarring. It is the authors' belief that the few reports of scarring with AFR[12,13] are likely the result of bulk heating and can be avoided with a careful treatment technique that minimizes overlap and allows time for adequate cooling of the skin.

Upon completion of the treatment, the protective eye shields were removed and gauze that was soaked in ice-cold water was applied to the treated skin. Pinpoint bleeding was easily controlled with brief pressure. Aquaphor Healing Ointment (Beiersdorf, Wilton, CT) was applied to the treated skin and the patient was bandaged with a protective sterile mask. The sterile mask (Exu-Dry; Smith & Nephew, Largo, FL) was secured with ties. It served to conceal and protect the treated skin during the patient's travel home, where it was then removed. Patients returned home with an escort and written instructions to soak the treated skin in water four times daily and keep the skin moist with Aquaphor at all times until crusting had resolved. Follow-up visits were generally scheduled for two days, one week, and one month posttreatment. As soon as crusting resolved, patients were instructed to switch from Aquaphor ointment to a nongreasy moisturizing cream in order to minimize the risk of acneiform eruptions.

When treating facial rhytides and photodamage with the Fraxel re:pair laser, energy fluences of 40 mJ to 70 mJ are typically used, with a coverage density of 30% to 50%. Coverage densities up to 60% may be used in patients with significant skin laxity and those with deep rhytides or scars. These parameters cannot be generalized to other fractionated CO_2 lasers because of variations in treatment handpieces and the maximal depth of ablation and coagulation, as mentioned previously. With all fractionated CO_2 lasers, however, the eyelids, neck, and chest should be treated more conservatively. The use of higher coverage densities or excessive energy on these areas can result in complications that include temporary ectropion and scarring.[12] The neck can tolerate energies used on the face; however, caution must be exercised to avoid bulk heating. Energy settings should be reduced when treating the eyelids and the chest. We typically reduce the energy settings by 50% when treating the eyelids. In addition, it is important to ask about a history of previous lower eyelid blepharoplasty. If a patient has had a lower eyelid blepharoplasty, it is advisable to treat the lower eyelids very conservatively or even avoid treating them, because these patients have an increased risk for lower eyelid ectropion following treatment.

The recovery time after a full-face AFR treatment is more rapid and predictable than that following tradition-

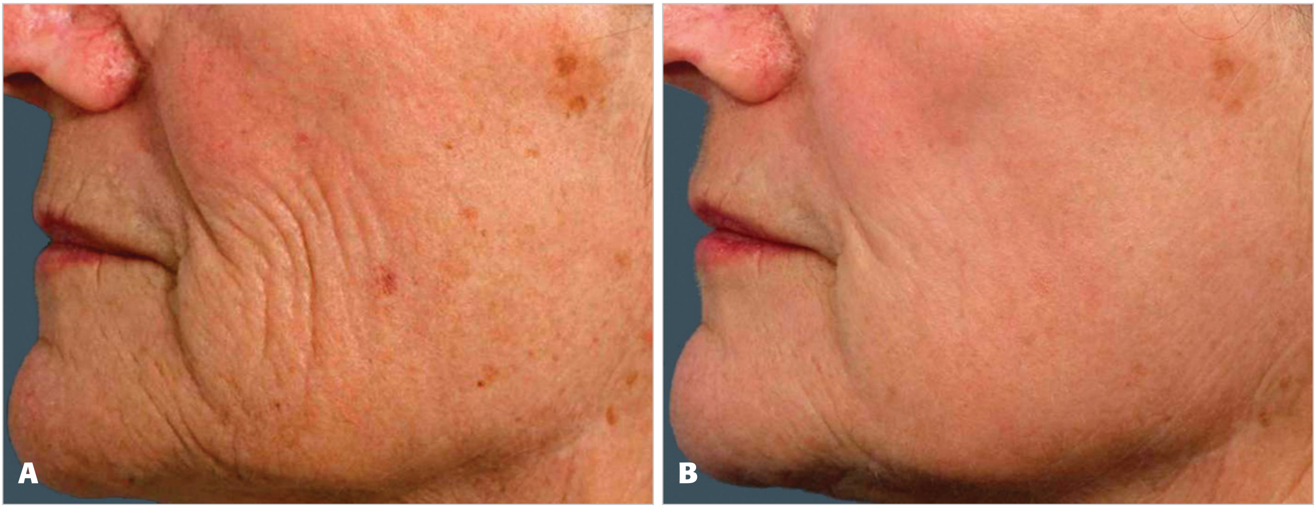

Figure 2. **A**, Pretreatement view of a 68-year-old woman. **B**, Three months after the second full-face ablative fractional resurfacing treatment, demonstrating an improvement in skin tone and reduction of facial rhytides.

al CO_2 laser resurfacing. AFR treatments result in immediate edema, oozing, crusting, and pinpoint bleeding at higher energy settings. Crusting typically resolves with complete reepithelialization, which occurs within three to six days. Once reepithelialization has occurred, the treated skin is generally quite red, but this erythema may be concealed with makeup. The erythema fades to pink and typically resolves over the course of several weeks. The intensity and time course of the erythema varies among patients, but it is generally more intense and slower to resolve in fair-skinned patients (Fitzpatrick skin phototypes I or II) and after more aggressive treatments. Although trace edema is often present at one-week follow-up visits, most patients begin to appreciate their cosmetic improvements at this time. Benefits of treatment include softening or disappearance of mild-to-moderate rhytides, improved skin texture and tone, decreased pore size, and a reduction in skin laxity. Figure 2 shows a 68-year-old woman who achieved considerable improvement in her rhytides, skin tone, and skin laxity following two full-face AFR treatments. Collagen production and remodeling continues for several months following treatment, with maximal benefit often realized three to six months after treatment. We have no experience combining AFR with elective surgery performed on the same day and, to our knowledge, this has not been studied.

In our practice, we have successfully used AFR to treat a variety of scars. AFR effectively flattens and smoothes hypertrophic scars and it increases collagen production beneath depressed, atrophic scars, resulting in normalization of the skin topography and overall cosmetic improvement. Clinical improvement can also be achieved in the treatment of hypopigmented scars, traumatic scars, cosmetic surgery scars, and other surgical scars (eg. from repairs following Mohs micrographic surgery). The proposed mechanism for improvement of hypopigmented scars is two-fold. First, it is believed that fractional injury to the skin facilitates the migration of melanocytes from neighboring healthy skin into the treated zones. Second, increased production of collagen in the papillary and upper reticular dermis changes the optical characteristics of the skin, softening the whiteness commonly seen in atrophic scars. Figure 3 shows a 52-year-old woman who presented with two depressed surgical scars on her nose. Two AFR treatments resulted in appreciable cosmetic improvement, specifically in terms of the depth and pigmentation of her scars.

AFR is particularly effective in the treatment of atrophic acne scarring. Patients undergoing two to three treatments with AFR were noted to have an average of 66% decrease in the depth of their acne scars.[15] Figure 4 shows a 38-year-old man who received three AFR treatments for severe acne scarring that had been present since adolescence. He experienced a reduction in the depth of his scars and a return of his natural pigmentation in many of his previously depigmented scars. When treating any type of scar, we often recommend a series of two to four treatments, with six to 12 weeks between treatments. Clinical improvement is evident after the initial treatment and improvement increases incrementally after each additional treatment. As stated above, maximal improvement resulting from collagen production and remodeling is realized several months after the final treatment.

Anecdotally, we have found AFR to be useful in the treatment of actinic cheilitis. Commonly accepted methods of treatment for actinic cheilitis include erbium or CO_2 laser ablation,[16,17] dermabrasion,[18] cryotherapy,[19] 5-fluorouracil,[20] photodynamic therapy,[21] and imiquimod.[22] With the appropriate treatment parameters—low energy and high density—AFR is effective in the treatment of actinic cheilitis and, as expected with fractional technology, healing is more rapid than is seen with fully ablative treatment modalities.

With AFR, we are also attaining considerable cosmetic benefit in the treatment of several other conditions—for example, the treatment of lower eyelid bags. In up to one-half of patients with lower eyelid bags, the underlying anatomic factor is one of dermatochalasis or orbicu-

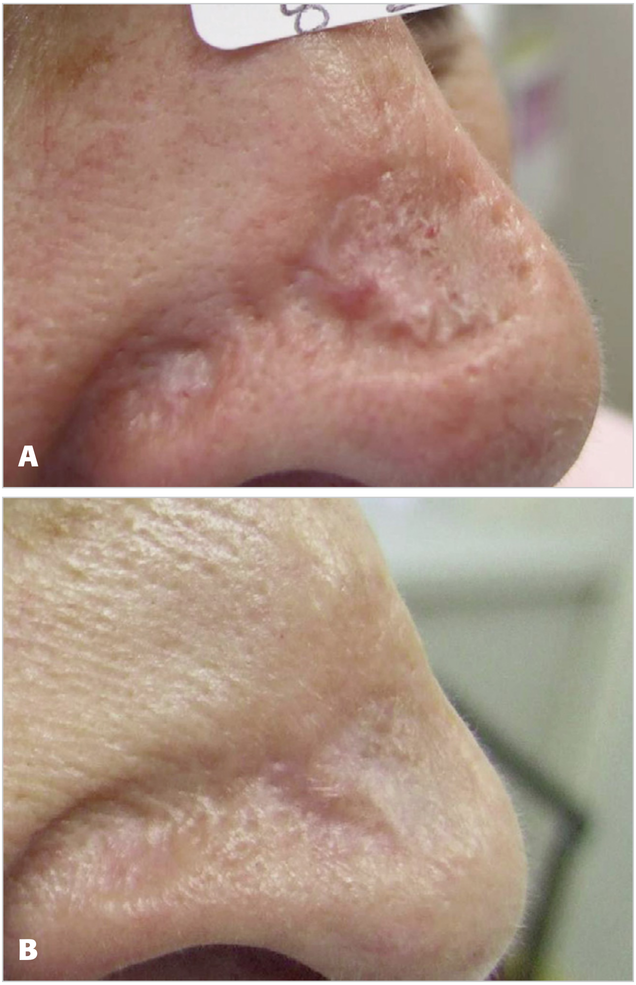

Figure 3. **A**, Pretreatment view of a 52-year-old woman. **B**, Two months after the second ablative fractional resurfacing treatment of two adjacent surgical scars on the nose, demonstrating a reduction in the depth of her scars and improvements in both skin texture and pigmentation.

laris oculi muscle festoons.[23] The term dermatochalasis refers to laxity of the eyelid skin. This laxity may be partially related to genetics and is exacerbated by both age and sun damage. Festoons, also called malar bags, are triangular-shaped malar pouches composed of redundant orbicularis oculi muscle with associated fat and overlying skin.[24] We have found AFR to be an effective, nonsurgical treatment for improving the appearance of both lower eyelid dermatochalasis and festoons. Figure 5 illustrates improvement in a 77-year-old woman's lower eyelid festoons three months after a single AFR treatment.

Future uses of AFR may include the treatment of skin textural abnormalities, such as the residual fibrofatty tissue from involuted infantile hemangiomas and silicone granulomas. FP with a 1440-nm wavelength was reported to improve the appearance of a single patient's residual hemangioma.[25] It is easy to accept that AFR, with a wavelength of 10600-nm and much deeper ablation and coagulation, can result in improved cosmesis and more appreciable tightening of fibrofatty hemangioma residual than a nonablative FP system. Silicone granulomas are situated in the dermis

Figure 4. **A**, Pretreatment view of a 38-year-old man. **B**, Three months after the third ablative fractional resurfacing treatment, demonstrating a reduction in the depth of his acne scars and improvement in the pigmentation of the scars.

and are therefore not affected by nonablative devices or traditional CO_2 lasers, but several passes with AFR focused directly over a silicone granuloma may effectively break up the granuloma and soften the appearance of the lesion.

Pigmentary disorders of the skin that are difficult to treat may also soon be treated with AFR. FP systems such as Fraxel re:store (Solta Medical) have demonstrated improvements in pigmentary disorders, such as melasma.[26-28] A pigmented handpiece with a larger (600-μm) spot size has been developed for the Fraxel re:pair laser, which uses AFR at lower energy fluences and greater coverage densities. The ActiveFX UltraScan computer pattern generator (CPG) delivery system (Lumenis, Santa Clara, CA), with its 1300-μm spot size, is also useful for treating dyschromia. Experience with the use of fractionated CO_2 lasers to treat pigmentary disorders is in its early stages; however, these devices appear to be useful in the treatment of melasma, infraorbital hyperpigmentation, hypopigmentation, and poikiloderma.

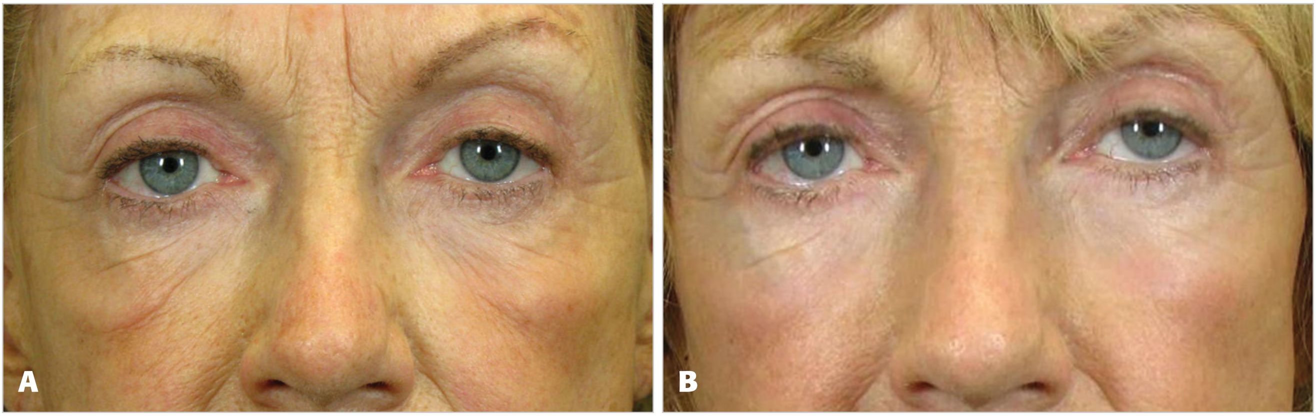

Figure 5. A, Pretreatment view of a 77-year-old woman. **B**, Three months after a single full-face ablative fractional resurfacing treatment, demonstrating improvement in her lower eyelid festoons.

CONCLUSIONS

AFR has become the most promising new option for safe, nonsurgical improvement in rhytides, photodamage, and scarring. With proper technique, results approaching those seen with traditional CO_2 laser resurfacing can be achieved with an exceedingly low risk of scarring and hypopigmentation. The relatively short recovery periods required after AFR treatments, combined with its safety and an expanding array of applications, are likely to ensure AFR's place in the cosmetic therapeutic arsenal for years to come.

DISCLOSURES

Dr. Geronemous is a shareholder and investigator for Solta Medical and is also a member of the medical advisory board for Lumenis. Drs. Hunzeker and Weiss have no financial interest in and receive no compensation from manufacturers of products mentioned in this article.

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