Fractional Photothermolysis: Current and Future Applications

Roy G. Geronemus, MD*
Laser & Skin Surgery Center of New York, New York, New York 10016-4974

Ablative lasers (CO_2 and Er:YAG) provide the greatest improvement in photoaging, but significant adverse effects limit their use. Nonablative lasers have reduced adverse effects, but limited efficacy. Fractional photothermolysis (FP) produces arrays of microscopic thermal wounds called microscopic treatment zones (MTZs) at specific depths in the skin without injuring surrounding tissue. Wounding is not apparent because the stratum corneum remains intact during treatment and acts as a natural bandage. Downtime is minimal and erythema is mild, permitting patients to apply cosmetics immediately after treatment. As with other nonablative laser modalities, multiple treatments are required. FP represents an alternative for treatment of dermatologic conditions without the adverse effects of ablative laser devices and can be used on all parts of the body. FP can be used for the treatment of facial rhytides, acne scars, surgical scars, melasma, and photodamaged skin. Lasers Surg. Med. 38:169–176, 2006.

Key words: infrared; intradermal focusing; laser; nonablative; photoaging; resurfacing

CONVENTIONAL LASERS

Introduced in 1983, the concept of selective photothermolysis (SP) offered a way to increase laser selectivity and reduce adverse effects associated with treatment [1]. The incident laser energy is confined to the target for a short time before it begins to diffuse to cooler surrounding tissues. To prevent heat-induced damage to surrounding tissues, laser energy is delivered in brief pulses rather than as a continuous beam. The goal is to deliver heat to the target in a time shorter than the time required for the heat to diffuse from the target to surrounding tissues such that heat is confined to the target [2].

SP has become a widely used approach for the selective photocoagulation of blood vessels, pigmented cells, and hair follicles [3]. Although SP has dramatically improved the efficacy and safety of lasers, the success of both ablative and nonablative laser treatments still depends on the skill of the operator. Ablative lasers are clinically effective, but have a high incidence of adverse effects, whereas nonablative techniques have reduced adverse effects but limited efficacy.

Both ablative and nonablative laser devices are used in skin resurfacing. Both types are designed to take maximum advantage of SP.

Targeted toward intracellular water, ablative CO_2 lasers emit light in the near infrared region at 10,600 nm. CO_2 radiation heats cells instantly to more than 100°C, resulting in: (1) vaporization and removal of a surface layer of cells; (2) coagulation necrosis of cells and denaturation of extracellular proteins in a subjacent residual layer; and (3) nonfatal damage to cells in a deeper zone [4]. The entire epidermis and varying thicknesses of the dermis are removed [5], and the patient's skin looks smoother and tighter during healing due to heat-induced shrinkage of collagen [6].

Although the pulsed CO_2 laser is the most effective modality for repairing photodamaged skin [5–12], patients frequently have post treatment edema, erythema, burning, and crusting. Erythema lasts for an average of 4.5 months [13]. Pigmentary changes, acne flares, herpes simplex virus (HSV) infection, scars, milia formation, and dermatitis may also occur [13–15]. Single-pass CO_2 laser resurfacing may reduce the severity of these adverse effects [16]. The adoption of the single-pass technique by many physicians appears to have reduced the morbidity associated with CO_2 laser treatment.

Also targeting intracellular water, the 2,940-nm Er:YAG laser is considered less ablative than the CO_2 laser. Er:YAG laser ablation is more superficial and wounds heal more quickly, but efficacy is less when fluences per pulse and number of passes similar to those of the CO_2 laser are used [4]. Er:YAG laser treatment also produces less dermal collagen remodeling than the CO_2 laser [15]. Although the Er:YAG laser has been used to treat solar elastosis and rhytides, efficacy increases with depth of thermal damage. As a result, the pulse duration of the Er:YAG must be increased to achieve the necessary depth of thermal damage [17]. Combining the CO_2 and Er:YAG lasers may be a treatment alternative to the CO_2 laser alone [18].

Nonablative laser procedures selectively injure the dermis but protect the epidermis by cooling during treatment [19–32]. Like ablative lasers, nonablative lasers emit coherent light at wavelengths absorbed by water. A nonablative 1,320-nm Nd:YAG laser and 1,450-nm

Dr. Geronemus is a shareholder in Reliant Technologies.

*Correspondence to: Roy G. Geronemus, MD, Laser & Skin Surgery Center of New York, 317 E 34th St, New York, NY 10016-4974. E-mail: mail@LaserSkinSurgery.com

Accepted 3 February 2006
Published online 20 March 2006 in Wiley InterScience (www.interscience.wiley.com).
DOI 10.1002/lsm.20310

semiconductor diode laser in combination with cryogen spray cooling have been used for the treatment of facial rhytides [24].

Nonablative laser procedures are better tolerated than ablative laser procedures. Although the wound response in the thermally injured dermis produces new collagen and repairs tissue defects from photoaging, nonablative laser techniques have less or unpredictable efficacy when compared with ablative laser techniques [3,33].

FRACTIONAL PHOTOTHERMOLYSIS

To overcome the disadvantages of conventional ablative and nonablative laser therapies, researchers have studied the clinical effects of fractional photothermolysis (FP) [15]. The basic concepts for these studies were introduced in 2003 [34] and reported in full during 2005 [3].

Khan and colleagues [3] used a 1,500-nm laser focused with objective lenses of high numerical aperture (resolving power) to produce arrays of microscopic columns of thermal injury surrounded by uninjured tissue. These arrays were produced in various patterns by focusing the laser beam at specific depths in the dermis. The result was spatially confined thermal damage in the dermis without surface cooling during irradiation and no epidermal injury. Areas of thermal damage (foci) were 50 to 150 μm in diameter, elliptical in shape, and located at specific depths (0–550 μm).

With proper choice of wavelength and focusing lens numerical aperture, even a low-power (1 W) diode laser could achieve high power densities at various intradermal depths. By adjusting laser parameters, the investigators could control the size, depth, and packing density of these foci of thermal injury. Exposure durations ranged from 3 to 30 milliseconds.

The tiny areas of thermal injury surrounded by uninjured tissue are called microscopic treatment zones (MTZs). The density of MTZs and the amount of space between them can be varied for a given energy level. For example, MTZ densities of 400, 1,600, and 6,400 MTZs/cm^2 correspond to inter-MTZ distances of 500, 250, and 125 μm, respectively [15]. The total density in a treatment session is calculated by multiplying the number of passes by the density setting.

To summarize, ablative and nonablative laser technologies produce layers of thermal heating whereas FP produces columns of thermal heating. Note also that photothermolysis refers to the destruction of tissue by radiation-induced thermal damage. In FP, tissue damage occurs in microscopic columns that extend into the dermis and is not restricted to a specific target tissue. Since each MTZ is surrounded by uninjured tissue, keratinocytes have a shorter migration path and healing is much quicker.

BIOLOGICAL AND CLINICAL EFFECTS OF FP

To evaluate the biological response and clinical effects associated with FP, Manstein and colleagues [15] treated human forearms and periorbital regions with a prototypic fractional laser treatment device (Reliant MTZ^{TM} SR, Reliant Technologies, Palo Alto, CA).

Biological Response

To test the effects of different MTZ densities (400, 1,600, and 6,400 MTZ/cm^2) on the skin, the forearms of 15 healthy subjects (skin types II–VI) were treated once with the FP device at 5 mJ energy without anesthesia or cooling. A built-in delay of 50 milliseconds between pulses prevented bulk heating. Histologic studies of tissue damage were conducted 3 months after treatment.

Typical MTZs penetrated to a depth of 300 μm and were 100 μm in diameter (Fig. 1). Re-epithelialization was complete 1 day after treatment. Healing was associated with the extrusion of damaged epidermal components—micro-epidermal necrotic debris (MENDS)—at MTZ margins. MENDS are button-shaped structures (40–80 μm diameter) that contain melanin and form beneath the intact stratum corneum above each dermal wound. The production of MENDS appeared to indicate a transition of keratinocytes to a wound-healing state as they participated in wound repair. MENDS formation was associated with the mild bronze color that developed in the treated areas and persisted for several weeks after treatment.

Histologic studies also showed increased mucin deposition and enhanced rete ridges within the superficial dermis.

The forearm study showed that MTZ densities of 1,600/cm^2 or less were well tolerated, and that side effects associated with ablative laser resurfacing were not observed in the treated areas.

Clinical Effects

The lateral periorbital wrinkles of 30 subjects were treated four times with a FP device equipped with a handheld scanner. Most participants were given topical anesthesia.

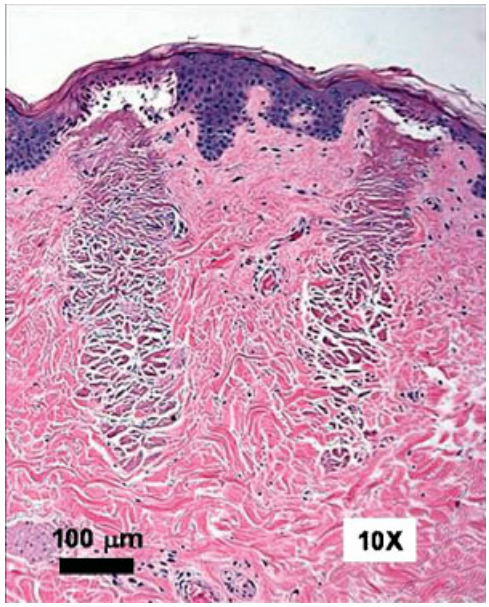

Fig. 1. Histologic slide of human skin after FP (15 mJ) demonstrating two microthermal zones at a depth of 560 μm and width of 135 μm.

The operator moved the scanner across the skin to deliver a specific laser pattern at an operator-selected spot density. The scanner did not adjust for hand motion speed, so exposure times were less than 5 milliseconds to minimize MTZ blurring. Each pulse produced 1 MTZ and was of 1.5 to 5 milliseconds duration.

In this study, the energy and wavelength were varied and the total MTZ density was kept constant. Each treatment consisted of 10 passes, 5 in one direction and 5 in a perpendicular direction. MTZs were deposited at 120/second and the average fluence per pass was 1.6 to 3 J/cm^2. Participants were evaluated for improvement in wrinkles, skin shrinkage, pain, and adverse effects.

Wrinkles and skin texture showed mild to moderate improvement 1 month and 3 months after the final treatment as estimated by patients and investigators. Blinded dermatologist investigators selected post treatment photographs as "better" overall in 96% of patient photographs. Average Fitzpatrick wrinkle scores 3 months after the final treatment showed a statistically significant improvement over pretreatment scores.

As for linear skin shrinkage, immediate shrinkage was noticeable within the first week, followed by relaxation at 1 month and retightening to 2.1% shrinkage 3 months after the final treatment.

Pain levels changed with successive passes and subsided within 10 to 60 minutes after treatment sessions. Pain does increase moderately with subsequent passes but disappears shortly after the treatment. Pain correlated with laser energies and did not change with treatment visits. Post treatment edema abated within 24 hours in 90% of patients. Erythema appeared within 1 day, declined quickly during the first week, and was nearly gone in 1 month. Pigmentary changes were not observed.

The authors concluded that: (1) a prototypic FP device had shown promising results; (2) side effects were reduced compared to those of ablative and nonablative modalities; and (3) further studies would more closely define the optimal parameters for the treatment of skin conditions.

The FDA has approved the Fraxel® Laser (Reliant Technologies, Palo Alto, CA) for treatment of pigmented

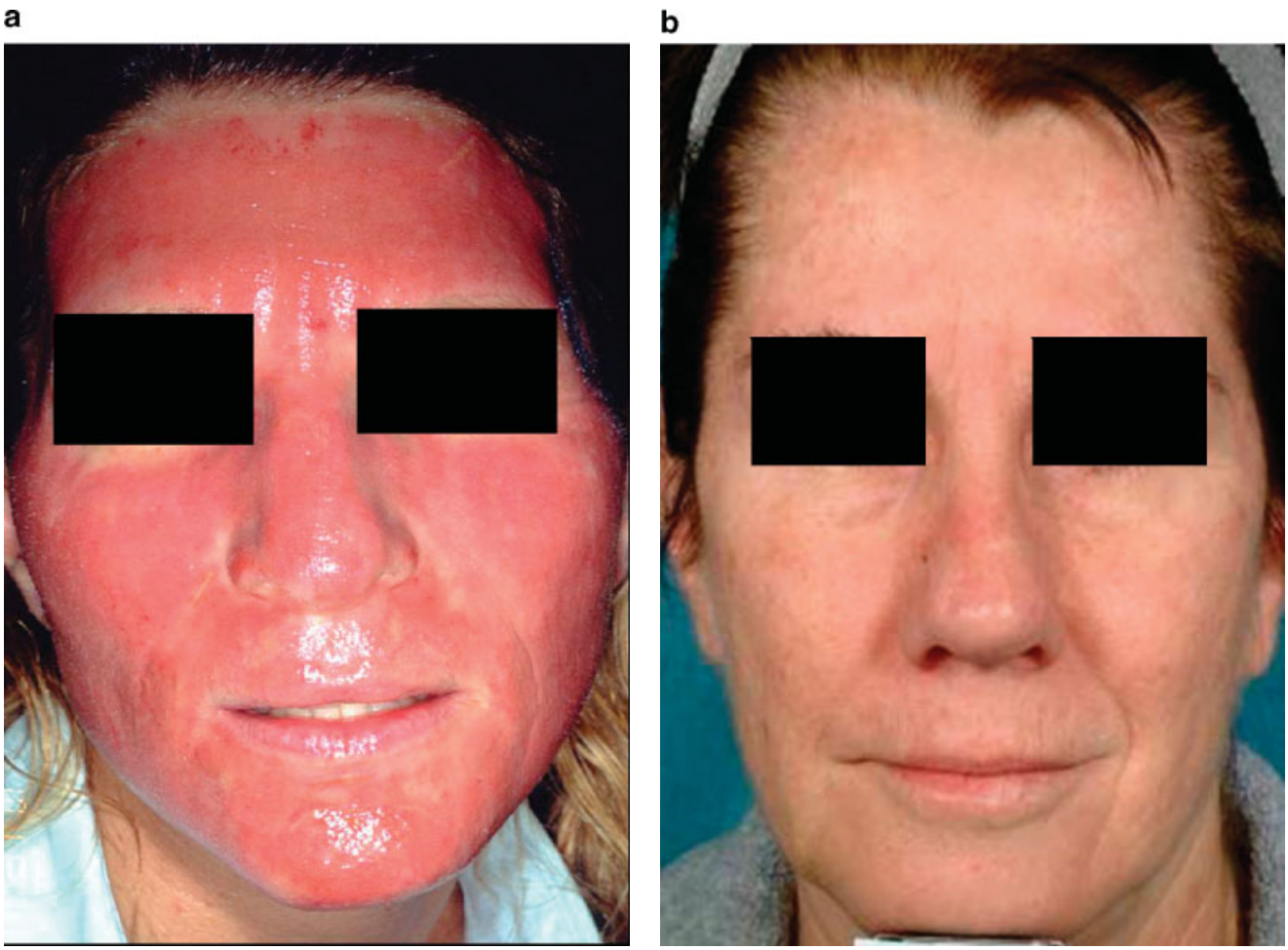

Fig. 2. **Left**: CO_2 laser resurfacing 1 day after treatment with ablation. **Right**: One day after FP with only mild redness and swelling.

lesions, periorbital rhytides, skin resurfacing, melasma, and soft tissue coagulation.

TREATMENT TECHNIQUES AND APPLICATIONS

Our in-office protocol for preparing patients for FP treatment requires: (1) wash the skin with cleanser then (2) prep the area with 70% alcohol; (3) painting with water-soluble blue tracking dye (Reliant Technologies); and (4) application of topical anesthesia ointment 1 hour before treatment. Care must be taken to not apply the dye in excess. Patients who find the preparatory time unacceptable are not suitable candidates for FP treatment.

Before laser treatment, blue dye (OptiGuide Blue, Reliant Technologies) is applied to the target areas. The blue dye does not interact with the laser; it provides contrast in the skin that allows the device's robotic system to track the velocity of the handpiece during treatment. The handpiece velocity determines the laser repetition rate to achieve a uniform pattern of MTZs. In other words, when the handpiece velocity decreases, the laser repetition rate is lower to maintain a uniform pattern of MTZ density. When the handpiece velocity increases, the laser repetition rate is higher. The blue dye provides the velocity data that allows the robotic system to alter the laser repetition rate that maintains a uniform pattern of MTZ density, thus assuring reproducible results. With this feature, the physician no longer needs to judge how fast to move the handpiece in order to provide a uniform treatment pattern.

After the blue dye is applied, a topical anesthesia ointment is applied to the target area. The handpiece tip is equipped with markings that help guide the physician during treatment. As the handpiece traverses the ointment-covered skin, the tip makes "tracks" in the ointment, revealing: (1) which areas of the skin have been treated; and (2) where to align the handpiece for the next treatment "stroke" to assure a pattern of uniform treatment density.

The use of the ointment tracks as a guide can be compared to mowing a lawn. As the operator moves the mower across the lawn, a "track" of which part of the lawn has been cut becomes visible. The operator uses this track as a guide to where to position the lawn mower for the next "stroke." The ointment tracks assist the physician in a similar manner.

The FP treatment protocol has been relatively uncomplicated and well accepted by patients. After the skin has been prepared as described above, 2,000 to 3,000 MTZ/cm^2 are delivered to the skin surface. Depending on the indication, the physician varies the energy laser level. Histology studies show that higher energies penetrate deeper into the skin [35]. For example, since dyschomias are superficial and acne scars are in deeper dermal areas,

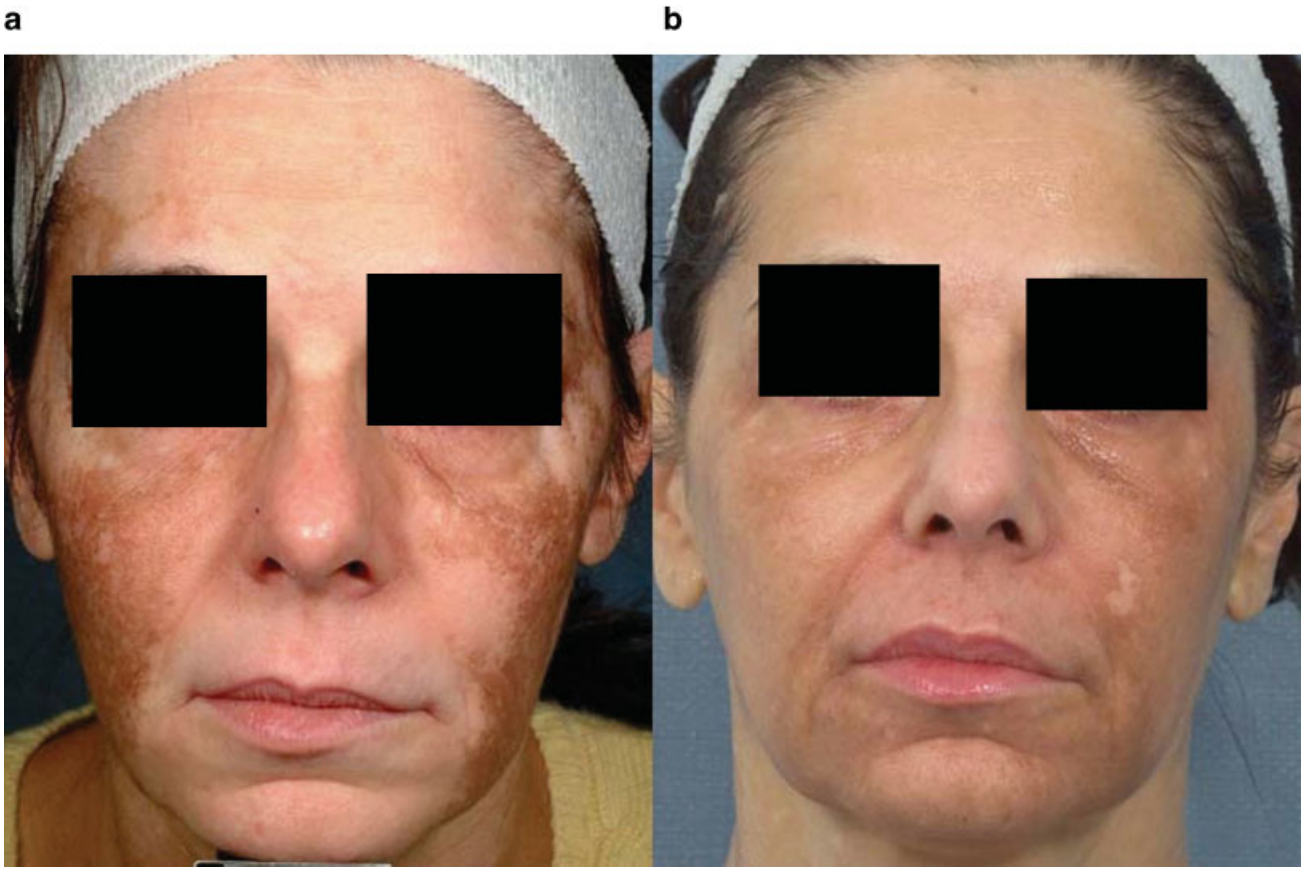

Fig. 3. **a**, **b**: A 48-year-old woman with epidermal and dermal melasma 5 months after her 5th FP treatment. Improvement of the melasma as well as her hypopigmentation is noted.

lower energies are required to treat dyschromias than are needed to treat acne scars. If more aggressive treatment is necessary, density settings are increased.

The procedure itself involves the contact application of the hand piece to the skin surface with approximately 2 to 4 kJ of energy delivered to the skin surface during the course of a full facial treatment. Most patients generally do not require postoperative skin care. Minor exfoliation or dryness can occur, and this requires the use of moisturizers. Sun avoidance is important to minimize post inflammatory hyperpigmentation, particularly in patients with darker skin phototypes. Patients who receive treatment on the upper cheeks and the lower eyelids sometimes receive a short course of systemic corticosteroids to minimize postoperative swelling. We do allow our patients to wear makeup after each treatment session, since there is no wounding of the skin in most cases.

In the fall of 2004, FP became commercially available for clinical use. Since that time, cooling during treatment, side effects, and efficacy in the treatment of photodamage, superficial rhytides, melasma, and scars (acne, traumatic, and surgical) have been studied.

For example, a study of 20 subjects receiving forced air cooling during FP treatment has been evaluated [36]. Physician-administered questionnaires revealed that 19 patients noted reduced pain with the addition of forced air cooling. Subsequently forced air cooling has become an integral part of our treatment regimen.

We also evaluated immediate and short-term side effects of FP in patients treated on the face, neck, chest, and hands [37]. Subsequent patients reported transient post treatment erythema (100%), xerosis (87%), facial edema (82%), flaking (60%), a few superficial scratches (47%), pruritis (37%), and bronzing (27%). The average pain score was 4.6 on a scale of 1 to 10. For most patients, social engagements were limited for 1 to 2 days. Long-lasting adverse events were not reported.

Over the short term, post treatment scarring, significant hyperpigmentation, hypopigmentation, and persistent bacterial infection were not observed, indicating that FP was well tolerated and safe (Fig. 2). HSV activation can occasionally be seen which may require prophylaxis on a case-by-case basis. Subsequently, the incidence of superficial scratches has diminished to close to zero as a consequence of hand piece modifications. Long-term hypopigmentation and scarring have not been seen in our experience.

While FP is not always curative for the treatment of melasma, its efficacy in a broad range of skin phototypes is well received by many patients who have suffered long-term with this condition (Fig. 3). We evaluated a case study of a patient who had failed conventional topical therapies for melasma. Tannous and colleagues [38] obtained a marked reduction in facial pigmentation (epidermal and dermal) 6 months after two full-face FP treatments spaced 3 weeks apart. The authors concluded that FP may be a safe and effective therapy for lightening both epidermal and dermal pigmentation associated with melasma. These results are significant because traditional laser therapy

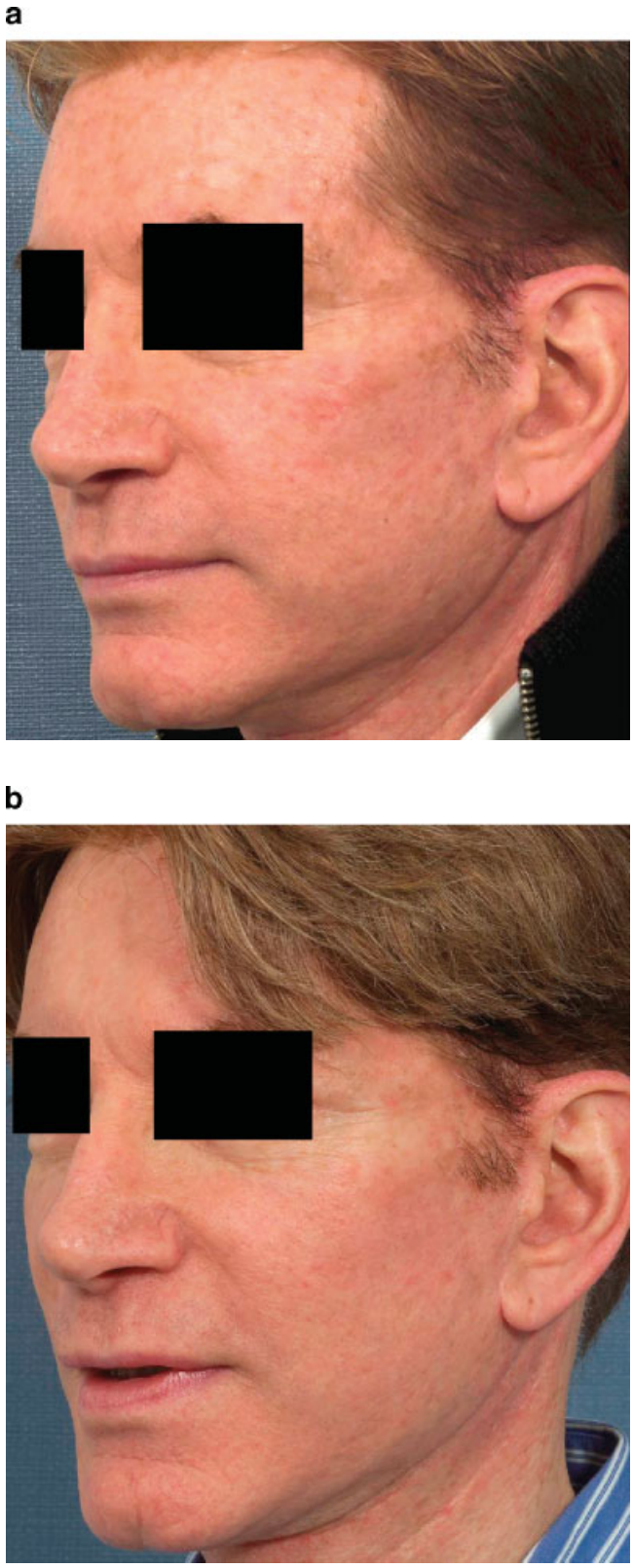

Fig. 4. A 40-year-old man with photodamage (a) before and (b) 3 months after five FP treatments.

has limited efficacy and a high incidence of post inflammatory hyperpigmentation when used to treat melasma [39,40]. We have also found the FP treatment of melasma to be particularly beneficial in patients with a wide variety of skin phototypes.

FP has been useful in the management of photodamage to the extent that solar lentigines, overall skin texture, and dilated pores tend to improve following a series of 3–5 treatment sessions. Many signs of photodamage tend to diminish gradually over a series of treatment sessions and the treatments can be spaced anywhere from 1–3 weeks apart (Fig. 4). FP has also been efficacious in my experience in the management of fine and moderate rhytides (Fig. 5). It is less efficacious in the management of deeper lines. For example, the vertical lines of the upper lip tend to improve but are not eliminated to the same degree as with a more aggressive ablative laser resurfacing technique or dermabrasion. In my experience, many patients accept the diminished success of deeper lines in exchange for the lower postoperative morbidity and significantly lower risk of pigmentary change.

One of the most significant advances in FP has been the ability to treat nonfacial areas, allowing for safe treatments on the neck, chest, back, and extremities. Ablative treatments on nonfacial areas can lead to scarring or hyperpigmentation that could be permanent or disfiguring. FP allows for safe and effective treatment of dyschromia, fine lines, and mild laxity as well as mild atrophic and hypertrophic scars in these nonfacial areas.

One of the more successful conditions treated by FP are acne scars (Fig. 6). Seventeen subjects with "ice-pick," "boxcar," and "rolling" scars received five FP treatments at 1- to 3-week intervals [41]. Mean improvement levels evaluated by digital photography, high-resolution typographic imaging, and patient-completed questionnaires ranged from 25% to 50%, 22% to 62%, and 29% to 67%, respectively. Patients experienced temporary post treatment erythema, mild facial edema, and moisturizer-responsive xerosis. Post treatment hyperpigmentation, hypopigmentation, and scarring were not observed. We have also seen favorable results when acne scars of patients with dark-skin phototypes were treated by FP.

The clinical indications for FP continue to expand. For example, evidence suggests that striae distensae can be improved through FP [42].

LIMITATIONS

Since FP is a new technique, our results must be regarded as preliminary. Long-term side effects and benefits have yet to be established. More patients treated by FP for a variety

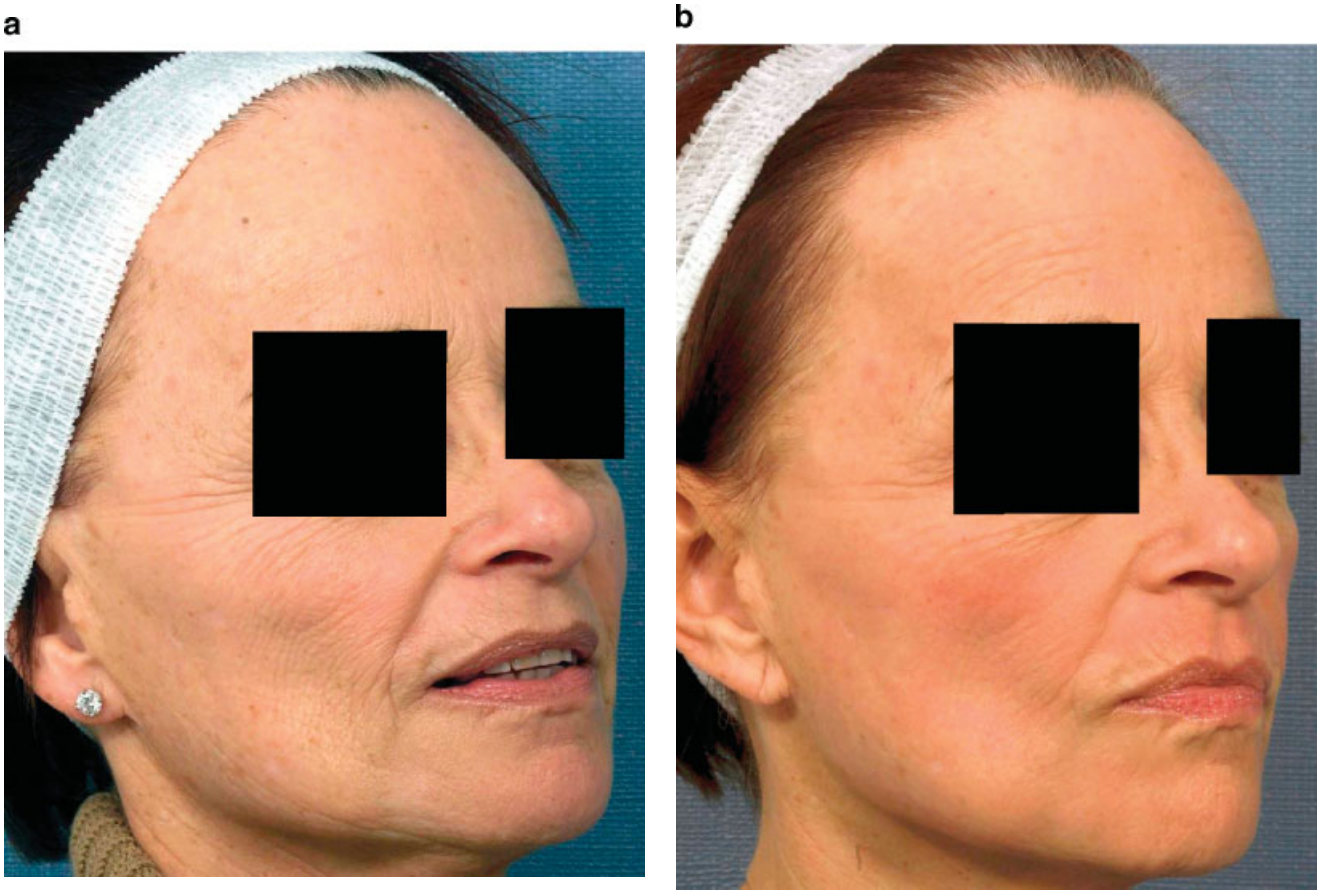

Fig. 5. A 55-year-old woman with moderate rhytides of the cheeks (a) before and (b) 2 months after five FP treatments.

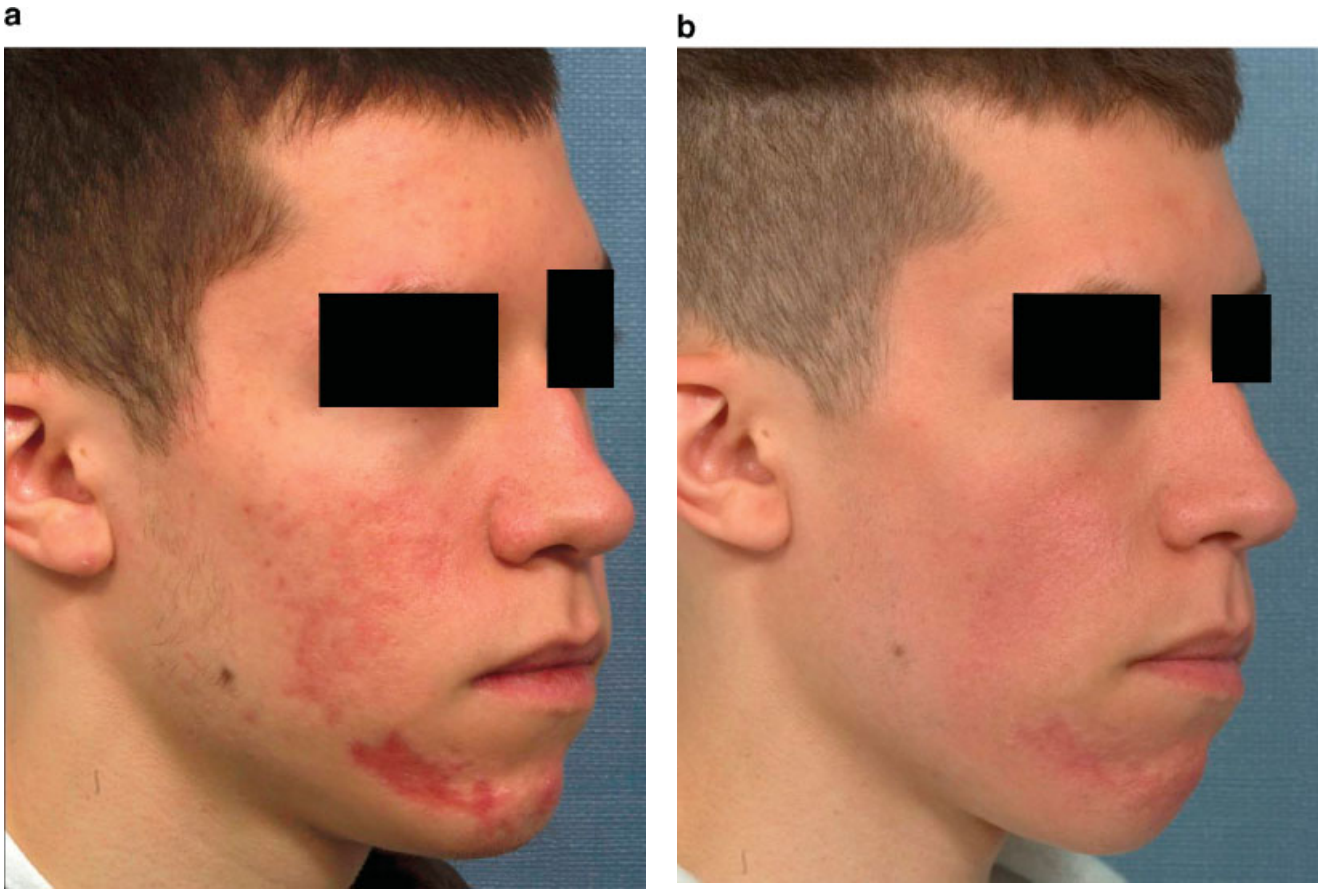

Fig. 6. A 19-year-old man with acne scarring (a) before and (b) 4 months after six FP treatments.

of conditions must be followed for long periods by other researchers to confirm our results. Treatment parameters must be continually refined to optimize outcomes and minimize inconvenience and expense to patients. To the author's knowledge, the effects of FP on erythema and telangiectasias have not been reported.

CONCLUSIONS

FP is a new approach to nonablative laser therapy in which an array of microscopic thermal wounds are created at controllable depths in the dermis. The technique coagulates both the epidermis and dermis without affecting the stratum corneum, which acts as a natural bandage that protects the tiny wounds as they heal. Treated zones are completely healed within 24 hours compared to 2 weeks for ablative laser resurfacing. Erythema is mild and patients can apply facial cosmetics immediately after treatment.

Like other nonablative technologies, FP requires multiple treatment sessions. In my experience, however, results comparable to those obtained after a series of FP sessions can be obtained with a single treatment with the Er:YAG laser or CO2 laser at least for facial wrinkles, and with at least 7 to 10 days downtime. FP has fewer and less severe side effects than ablative resurfacing and, with the exception of deep rhytides, the results in terms of skin tone, texture, dyschromia, and scars are essentially equivalent. These benefits are seen without many of the risks associated with ablative resurfacing.

In conclusion, our experience and early reports suggest that the FP technology is a safe and effective alternative for the treatment of superficial rhytides, acne scars, some surgical scars, melasma, and photodamaged skin.

ACKNOWLEDGMENTS

Dr. Kin Chan graciously assisted in the preparation of the histologic photomicrograph.

REFERENCES

1. Anderson RR, Parrish JA. Selective photothermolysis: Precise microsurgery by selective absorption of pulsed radiation. Science 1983;220:524–527.
2. McKenzie AL. Physics of thermal processes in laser-tissue interaction. Phys Med Biol 1990;35:1175–1209.
3. Khan MH, Sink RK, Manstein D, Eimerl D, Anderson RR. Intradermally focused infrared laser pulses: Thermal effects at defined tissue depths. Lasers Surg Med 2005;36: 270–280.
4. Khatri KA, Ross V, Grevelink JM, Magro CM, Anderson RR. Comparison of erbium:YAG and carbon dioxide lasers in

resurfacing of facial rhytides. Arch Dermatol 1999;135:391–397.
5. Fitzpatrick RE, Goldman MP, Satur NM, Tope WD. Pulsed carbon dioxide laser resurfacing of photo-aged facial skin. Arch Dermatol 1996;132:395–402.
6. Hruza GJ, Dover JS. Laser skin resurfacing. Arch Dermatol 1996;132:451–455.
7. Waldorf HA, Kauvar AN, Geronemus RG. Skin resurfacing of fine to deep rhytides using a char-free carbon dioxide laser in 47 patients. Dermatol Surg 1995;21:940–946.
8. Lowe NJ, Lask G, Griffin ME. Laser skin resurfacing. Pre- and post treatment guidelines. Dermatol Surg 1995;21:1017–1019.
9. Lowe NJ, Lask G, Griffin ME, Maxwell A, Lowe P, Quilada F. Skin resurfacing with the Ultrapulse carbon dioxide laser. Observations on 100 patients. Dermatol Surg 1995;21:1025–1029.
10. Lask G, Keller G, Lowe N, Gormley D. Laser skin resurfacing with the SilkTouch flashscanner for facial rhytides. Dermatol Surg 1995;21:1021–1024.
11. David LM, Sarne AJ, Unger WP. Rapid laser scanning for facial resurfacing. Dermatol Surg 1995;21:1031–1033.
12. Ho C, Nguyen Q, Lowe NJ, Griffin ME, Lask G. Laser resurfacing in pigmented skin. Dermatol Surg 1995;21:1035–1037.
13. Nanni CA, Alster TS. Complications of carbon dioxide laser resurfacing. An evaluation of 500 patients. Dermatol Surg 1998;24:315–320.
14. Bernstein L, Kauvar A, Grossman M, Geronemus R. The short and long term side effects of carbon dioxide laser resurfacing. Dermatol Surg 1997;23:519–525.
15. Manstein D, Herron GS, Sink RK, Tanner H, Anderson RR. Fractional photothermolysis: A new concept for cutaneous remodeling using microscopic patterns of thermal injury. Lasers Surg Med 2004;34:426–438.
16. Alster T, Hirsch R. Single-pass CO_2 laser skin resurfacing of light and dark skin: Extended experience with 52 patients. J Cosmet Laser Ther 2003;5:39–42.
17. Ross EV, McKinlay JR, Sajben FP, Miller CH, Barnette DJ, Meehan KJ, Chhieng NP, Deavers MJ, Zelickson BD. Use of a novel erbium laser in a Yucatan minipig: A study of residual thermal damage, ablation, and wound healing as a function of pulse duration. Lasers Surg Med 2002;30:93–100.
18. Millman AL, Mannor GE. Combined erbium:YAG and carbon dioxide laser skin resurfacing. Arch Facial Plast Surg 1999;1:112–116.
19. Goldberg DJ, Whitworth J. Laser skin resurfacing with the Q-switched Nd:YAG laser. Dermatol Surg 1997;23:903–906.
20. Herne KB, Zachary CB. New facial rejuvenation techniques. Semin Cutan Med Surg 2000;19:221–231.
21. Bjerring P, Clement M, Heickendorff L, Egevist H, Kiernan M. Selective non-ablative wrinkle reduction by laser. J Cutan Laser Ther 2000;2:9–15.
22. Ross EV, Sajben FP, Hsia J, Barnette D, Miller CH, McKinlay JR. Nonablative skin remodeling: Selective dermal heating with a mid-infrared laser and contact cooling combination. Lasers Surg Med 2000;26:186–195.
23. Menaker GM, Wrone DA, Williams RM, Moy RL. Treatment of facial rhytides with a nonablative laser: A clinical and histologic study. Dermatol Surg 1999;25:440–444.
24. Kelly KM, Nelson JS, Lask GP, Geronemus RG, Bernstein LJ. Cryogen spray cooling in combination with nonablative laser treatment of facial rhytides. Arch Dermatol 1999;135:691–694.
25. Goldberg DJ. Full-face nonablative dermal remodeling with a 1320 nm Nd:YAG laser. Dermatol Surg 2000;26:915–918.
26. Trelles MA, Allones I, Luna R. Facial rejuvenation with a nonablative 1320 nm Nd:YAG laser: A preliminary clinical and histologic evaluation. Dermatol Surg 2001;27:111–116.
27. Levy JL, Trelles M, Lagarde JM, Borrel MT, Mordon S. Treatment of wrinkles with the nonablative 1,320-nm Nd:YAG laser. Ann Plast Surg 2001;47:482–488.
28. Lupton JR, Williams CM, Alster TS. Nonablative laser skin resurfacing using a 1540 nm erbium glass laser: A clinical and histologic analysis. Dermatol Surg 2002;28:833–835.
29. Fournier N, Dahan S, Barneon G, Rouvrais C, Diridollou S, Lagarde JM, Mordon S. Nonablative remodeling: A 14-month clinical ultrasound imaging and profilometric evaluation of a 1540 nm Er:Glass laser. Dermatol Surg 2002;28:926–931.
30. Mordon S, Capon A, Creusy C, Fleurisse L, Buys B, Faucheux M, Servell P. In vivo experimental evaluation of skin remodeling by using an Er:Glass laser with contact cooling. Lasers Surg Med 2000;27:1–9.
31. Fournier N, Dahan S, Barneon G, Diridollou S, Lagarde JM, Gall Y, Mordon S. Nonablative remodeling: Clinical, histologic, ultrasound imaging, and profilometric evaluation of a 1540 nm Er:glass laser. Dermatol Surg 2001;27:799–806.
32. Muccini JA Jr, O'Donnell FE Jr, Fuller T, Reinisch L. Laser treatment of solar elastosis with epithelial preservation. Lasers Surg Med 1998;23:121–127.
33. Grema H, Greve B, Raulin C. Facial rhytides—Subsurfacing or resurfacing? A review. Lasers Surg Med 2003;32:405–412.
34. Huzaira M, Anderson RR, Sink K, Manstein D. Intradermal focusing of near-infrared optical pulses: A new approach for non-ablative laser therapy. Lasers Surg Med 2003;32(Suppl 15):17–38.
35. Data on file, Reliant Technologies, Inc.
36. Fisher GH, Kim KH, Bernstein LJ, Geronemus RG. Concurrent use of a handheld forced cold air device minimizes patient discomfort during fractional photothermolysis. Dermatol Surg 2005;31(9 Pt 2):1242–1243.
37. Fisher GH, Geronemus RG. Short-term side effects of fractional photothermolysis. Dermatol Surg 2005;31(9 Pt 2):1245–1249.
38. Tannous ZS, Astner S. Utilizing fractional resurfacing in the treatment of therapy-resistant melasma. J Cosmet Laser Ther 2005;7:39–43.
39. Taylor CR, Anderson RR. Ineffective treatment of refractory melasma and postinflammatory hyperpigmentation by Q-switched ruby laser. J Dermatol Surg Oncol 1994;20:592–597.
40. Nouri K, Bowes L, Chartier T, Romagosa R, Spencer J. Combination treatment of melasma with pulsed CO2 laser followed by Q-switched alexandrite laser: A pilot study. Dermatol Surg 1999;25:494–497.
41. Fisher GH, Skover G, Geronemus RG. Treatment of acneiform scars with fractional photothermolysis. Lasers Surg Med 2005; April
42. Bernstein LJ, Kim K, Chapas A, Geronemus R. Treatment of striae distensae with fractional photothermolysis. Paper presented at: 25th Annual Scientific Meeting of the American Society of Laser Medicine and Surgery held in Orlando, Florida on March 30-April 1, 2005.