

The spectrum of laser skin resurfacing: Nonablative, fractional, and ablative laser resurfacing

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The drive to attain cosmetic facial enhancement with minimal risk and rapid recovery has inspired the field of nonsurgical skin rejuvenation. Laser resurfacing was introduced in the 1980s with continuous wave carbon dioxide (CO₂) lasers; however, because of a high rate of side effects, including scarring, short-pulse, high-peak power, and rapidly scanned, focused-beam CO₂ lasers and normal-mode erbium-doped yttrium aluminium garnet lasers were developed, which remove skin in a precisely controlled manner. The prolonged 2-week recovery time and small but significant complication risk prompted the development of non-ablative and, more recently, fractional resurfacing in order to minimize risk and shorten recovery times. Nonablative resurfacing produces dermal thermal injury to improve rhytides and photodamage while preserving the epidermis. Fractional resurfacing thermally ablates microscopic columns of epidermal and dermal tissue in regularly spaced arrays over a fraction of the skin surface. This intermediate approach increases efficacy as compared to nonablative resurfacing, but with faster recovery as compared to ablative resurfacing. Neither nonablative nor fractional resurfacing produces results comparable to ablative laser skin resurfacing, but both have become much more popular than the latter because the risks of treatment are limited in the face of acceptable improvement. (J Am Acad Dermatol 2008;58:719-37.)

Learning objectives: At the completion of this learning activity, participants should be familiar with the spectrum of lasers and light technologies available for skin resurfacing, published studies of safety and efficacy, indications, methodologies, side effects, complications, and management.

NONABLATIVE RESURFACING

Nonablative laser systems

Although the carbon dioxide (CO₂) and erbium-doped yttrium aluminium garnet (Er:YAG) lasers remain the gold standards for rejuvenating photo-damaged skin, their use is associated with significant risk of side effects and a prolonged and an unpleasant postoperative recovery period. Newer rejuvenating laser systems have been introduced in an effort to stimulate collagen production and remodeling with little or no healing time and less

patient discomfort. These systems can be classified into 3 main groups: mid-infrared lasers that target the dermis and are used for nonablative resurfacing; visible lasers such as the pulsed dye laser (PDL) and the pulsed 532-nm potassium titanyl phosphate (KTP) laser, alone or in conjunction with the 1064-nm neodymium yttrium aluminium garnet (Nd:YAG) laser; and intense pulsed light (IPL) sources.^{1,2}

Initially, the Q-switched Nd:YAG laser at 1064 nm, either alone or in combination with a carbon particle solution, was shown to induce some dermal remodeling.^{3,4} Subsequently, vascular lasers, such as the PDL or pulsed 532-nm lasers were used, with minimal efficacy as discussed later. The use of these aforementioned lasers has been largely replaced by the longer wavelength infrared lasers, which more effectively target the mid dermis, resulting in more consistent mild improvement in rhytides. IPL devices combine the targeting of dyspigmentation and vascularity with longer wavelengths, thereby resulting in global improvement in photodamage. More recently, radiofrequency systems have been utilized to deliver electrical energy with or without laser and light concomitantly, resulting in more pronounced

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effects on skin laxity and rhytid reduction. Photothermal and other effects result in collagen contracture and new collagen formation.

Vascular lasers

A possible role for PDLs in the treatment of photoaged skin had long been suggested by the apparent clinical and histologic collagen changes induced in PDL-treated hypertrophic scars, striae distensae, and acne scars.⁵⁻¹² The first to be utilized for wrinkle reduction was the 585-nm PDL (N-lite) at 350-microsecond and subpurpuric fluences. A clinical study using single PDL treatments (585-nm, 450-microsecond) demonstrated a clinical improvement in 75% to 90% of mild to moderate wrinkles and 40% in moderate to severe rhytides.¹³ Histologic examination of the treated areas showed an increased amount of normal staining in elastin and collagen fibers in the papillary dermis, with increased cellularity and mucin deposition. Although another initial study demonstrated significant reduction in rhytides, further studies were unable to reproduce these findings and demonstrated only minimal effects.¹⁴ The long-pulsed (LP) PDL at 595 nm demonstrated an 18% improvement in clinical grading of photodamage in one study.¹⁵ This result was largely related to the laser's ability to target facial telangiectasia associated with photodamage.¹⁶ Despite approval by the US Food and Drug Administration (FDA) for treating photodamage with the LP PDL, only modest results have been observed with these short wavelengths, presumably because of predominantly vascular targeting and superficial penetration to the papillary dermis.

Recently, the application of the precursor photosensitizer aminolevulinic acid (ALA) in combination with the LP PDL has enhanced the ability of this laser to treat photoaging.¹⁷ Photodynamic therapy mediated by LP PDL is effective in the removal of actinic keratoses (AK), actinic cheilitis (AC), lentigines, fine rhytides, and textural changes caused by photoaging.¹⁷⁻¹⁹ The mechanism of this effect appears to be the activation by the LP PDL at 595 nm of the photosensitizer protoporphyrin IX which preferentially accumulates in photodamaged cells, resulting in their destruction either by apoptosis or an immune-mediated response. Thus, the effects of PDL on photodamaged skin have been significantly augmented by ALA application.

Intense pulsed light

The advantage of intense pulsed light (IPL; 550-1200 nm) is its ability to target both melanin and hemoglobin, resulting in global improvement in dyspigmentation and vascularity. The term

“photorejuvenation” was coined in describing the global improvement in multiple parameters of photoaging that is observed with the IPL. Filters may be placed to exclude shorter wavelengths, thereby preferentially targeting various chromophores. Its use for wrinkle reduction has been assessed with evidence of histologic neocollagenesis 6 months after treatment.²⁰ The patient perception of improvement is increased likely because of apparent decreases in dyspigmentation and vascularity, which are more easily detectable than mild changes in rhytides, therefore placing this device in the mainstream of nonablative resurfacing.

The use of IPL has led to modest clinical improvement in rhytides, although pigment and vascular abnormalities of photodamaged skin show dramatic improvement.²¹ This was accompanied by histologic changes indicative of a dermal remodeling effect, such as an increase in extracellular matrix proteins and neocollagenesis.²² With the addition of 5-ALA before each of a series of IPL treatment, greater pigmentary and vascular improvement is achieved while increasing the degree of improvement of fine wrinkles.^{23,24} The use of photodynamic therapy (PDT) in photorejuvenation and the treatment of photoaging is covered in a separate section.

Infrared lasers

The prototype of nonablative rejuvenation is the infrared Nd:YAG laser at 1320 nm with a pulse duration of 200 microseconds (CoolTouch; ICN Photonics, Costa Mesa, Calif)²⁵ and, more recently, the diode laser at 1450 nm (Smoothbeam; Candela, Wayland, Mass) and the erbium:glass laser at 1540 microseconds.²⁶ Multiple clinical studies employing this method have demonstrated mild but reproducible improvement in rhytides and scars, with histologic evidence of neocollagenesis 6 months after treatment.²⁷ In two studies using the 1320-nm Nd:YAG laser, the majority demonstrated minimal to mild improvement, with the minority demonstrating moderate improvement.^{25,28} Similar results have been obtained using the 1450-nm diode, which has been shown to result in mild improvement of periorbital and perioral rhytides.²⁹ Treatment with a 1540-nm erbium-doped phosphate glass laser has shown to result in mild to moderate improvement in rhytides, with a histologic increase in dermal collagen 2 months after treatment.³⁰ Another study of 60 patients with periorbital and perioral rhytides treated with the 1540-nm erbium-doped phosphate glass laser demonstrated a mean increase in dermal thickness of 17% and a patient satisfaction rate of 62%.³¹ The Nd:YAG 1320-nm laser was shown to be efficacious for the treatment of acne scarring.³² In a

comparative study of the 1450-nm diode and the 1320-nm Nd:YAG lasers in treating atrophic facial scars, the 1450-nm diode was shown to be more efficacious.³³ The drawback of infrared laser non-ablative skin rejuvenation is that it induces only dermal changes and, therefore, has a limited benefit for patients with photoaging who have both epidermal and dermal changes. It is best suited for the treatment of the wrinkles associated with photoaging and in the treatment of acne scarring.

Histochemical analysis of nonablative resurfacing following the use of 1320-nm Nd:YAG laser has demonstrated both epidermal and dermal changes. Three passes with the laser were required to result in epidermal spongiosis and basal cell layer edema 1 hour after treatment and in the dermal changes of microthrombi, sclerosis of blood vessels, and neutrophilic infiltration at 3 days. These findings correlated with clinical improvement, suggesting that epidermal and vascular injury may play a role.³⁴ The 1450-nm laser has been shown to result in fibrosis of the upper dermis, and the 1540-nm erbium-doped phosphate glass laser to result in an increase in dermal thickness.^{30,33} The clinical findings have been shown to correlate with histologic increases in dermal collagen following nonablative laser rejuvenation employing infrared wavelengths over a 3- to 6-month period.^{27,29,30,33,35}

Recently, a new infrared device emitting wavelengths from 1100 to 1800 nm has been introduced for the treatment of skin laxity. This technology is postulated to function by causing volumetric heating of the dermis, which is followed by tissue contraction. To date, early data suggest its safety and moderate degree of efficacy in treating rhytides and laxity. In one preliminary study of 25 patients, fluences of 20 to 30 J/cm² produced immediate changes and moderate improvement in rhytides of facial skin.³⁶ In a preliminary split-face design study comparing this modality to radiofrequency, discussed later, a more mild improvement was reported using the infrared device.³⁷ In another study, mild improvements were reported in the majority with dramatic findings in a minority of patients treated.³⁸

Radiofrequency

In an effort to increase penetration depth and strive towards collagen shrinkage and skin tightening, radiofrequency wavelengths have been extensively employed.³⁹ Radiofrequency devices produce electrical energy that heats the dermis without plume and at relatively low temperatures. The first energy source in this arena was the monopolar radiofrequency device, ThermoCool

(Thermage, Inc, Hayward, Calif), which demonstrated improvement in skin laxity on the face and neck. This technology delivers a uniform volumetric heating effect into the reticular dermis, generated by the tissue's resistance to the current flow. The electric field polarity is changed 6 million times per second, causing the charged particles within the electric field to change orientation at that frequency. Heat is generated by the resistance of the tissue to the particular movements. Advantages include the minimal erythema postoperatively that typically resolves within hours and lack of significant risk of side effects. Early on disadvantages of that system were inconsistent results, including dramatic improvement in a minority of patients and minimal changes in the majority.⁴⁰ In one study of the ThermoCool TC system used to treat the lower face of 16 patients, only 5 of 15 patients polled (one-third) considered the results satisfactory. Photographic analysis did not yield statistically significant results.⁴¹ Recent technological and technique modifications have dramatically improved the consistency and extent of improvement with ThermoCool treatments by increasing the tip size and repeatedly treating over the indicated area as many as 5 times at lower energy settings.⁴²

The combination of electrical and optical energy has been achieved in order to augment the non-ablative effects achieved by either modality alone. The combination of infrared laser at 900 nm and bipolar radiofrequency (RF) and of IPL (500-1200 nm) at lower fluences with bipolar RF has been evaluated for the systematic reduction of all aspects of photodamage and rhytides.⁴³⁻⁴⁵ The combination of RF with diode laser and with pulsed light has been shown to induce tissue contraction and effects on laxity, rhytides, and other aspects of photodamage.⁴⁵ This combination technology has also been assessed for striae (M.A.A., unpublished data) and cellulite.⁴⁶ Despite these studies demonstrating safety and efficacy in treating photodamage, rhytides, and laxity, the comparison control of the laser or pulsed light without RF is lacking, which would test the hypothesis regarding a synergistic effect of the RF on outcome. An example of a patient before and after a single treatment with a combination of RF and infrared laser and pulsed light is shown in Fig 1, A and B, respectively. Progressive improvement following RF generally takes place over a 3-month period, though continued improvement may be observed up to 1 year (Fig 2, A-C).

Newer radiofrequency technologies are continually being developed to promote the degree of skin tightening in fewer treatments. The most recent advent is the Accent device (Alma Lasers, Ltd,

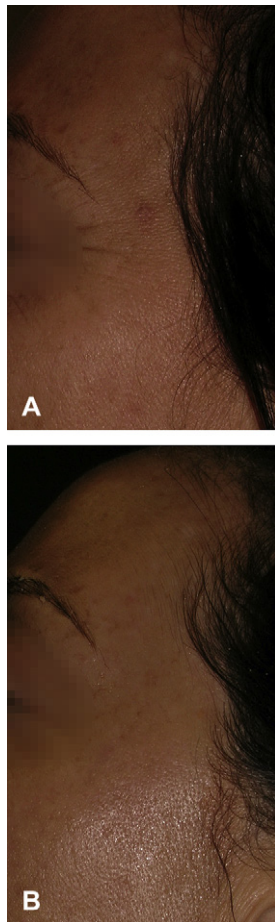


Fig 1. Combination 900-m diode laser, pulsed light, and radiofrequency for the treatment of rhytides, laxity, and photoaging. A photographic example of a patient with periorbital rhytides and photoaging before (A) and after (B) 2 treatments at 6-month follow-up. (Reproduced with permission from the *Journal of Drugs in Dermatology*: Alexiades-Armenakas MR. Rhytides, laxity, and photo-damage treated with a combination of radiofrequency, diode laser, and pulsed light and assessed with a comprehensive grading scale. *J Drugs Dermatol* 2006;7(8):731-8.)

Caesarea, Israel), which offers alternatively bipolar and a novel unipolar RF modes.^{39,47} The unipolar handpiece generates 40.84 MHz of RF electromagnetic radiation, not current, thereby precluding the need for grounding. The unipolar mode achieves a penetration depth of 20 mm, while the bipolar handpiece delivers RF current to a 2- to 6-mm penetration depth. A randomized, split-face trial employing unipolar on one side and bipolar on the contralateral side, with blinded evaluations employing the comprehensive grading scale, demonstrated improvement in rhytides and laxity with both the unipolar and bipolar modalities.⁴⁷ Another randomized, split-site, controlled, and blinded evaluated study of cellulite on thighs demonstrated significant

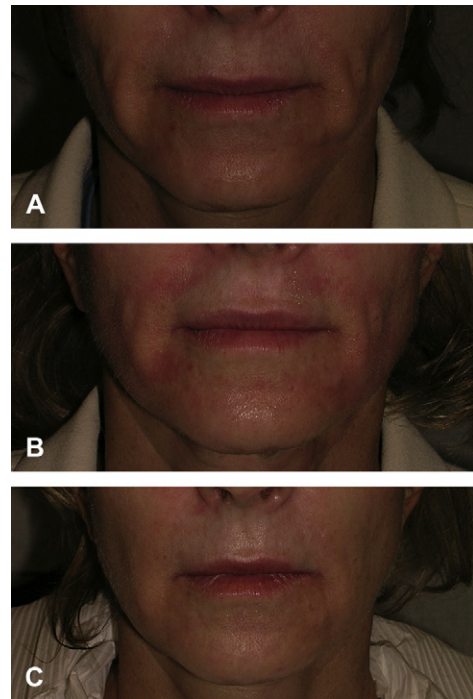


Fig 2. Combination 900-nm diode laser, pulsed light, and radiofrequency for the treatment of rhytides, laxity, and photoaging. Patient before (A) a single treatment with a significant reduction in lower facial laxity observed immediately following treatment (B) and a marked improvement at 1-year follow-up (C). (Courtesy M. R. Alexiades-Armenakas, MD, and reproduced in part with permission from the *Journal of Drugs in Dermatology*: Alexiades-Armenakas MR. Rhytides, laxity, and photo-damage treated with a combination of radiofrequency, diode laser, and pulsed light and assessed with a comprehensive grading scale. *J Drugs Dermatol* 2006;7(8):731-8.)

improvement on the treated side versus control following a mean of 4 treatments.⁴⁸ The unipolar mode targets the reticular dermis and subcutaneous junction, whereas the bipolar mode targets the papillary and mid dermis, thereby theoretically improving both laxity and fine lines through a combined approach.

Photodynamic therapy. The treatment of photoaging through nonablative photorejuvenation encompasses the use of PDT.¹⁹ The application of topical photosensitizers, namely 5-ALA, for short incubation times combined with newer laser and light sources has been shown to be safe and effective for the treatment of AK, AC, photodamage, and for photorejuvenation with minimal side effects.¹⁹ ALA PDT is predominantly combined with blue light LP PDL or IPL. The use of methyl-ALA (MAL) and red light has been developed for AK and potentially basal cell carcinoma treatment, although it has not yet been investigated for photorejuvenation.⁴⁹

Sample protocols employing PDT with these photosensitizers and light sources for photorejuvenation are listed in Table I.

Blue light. Topical ALA and blue light achieved FDA approval for the treatment of AK in 1997.⁵⁰ In the phase III study, which was randomized, placebo-controlled, and investigator-blinded, 89% of patients achieved greater than 75% clearing of AK at a 12-week follow-up following 1 to 2 treatments with ALA and blue light.⁵¹ ALA with blue light has since been shown to be effective in short, 1-hour incubation periods in treating diffuse photodamage and AK (Table I).⁵²

LP PDL. In the first study of LP PDL PDT of 41 patients with AK, ALA was applied for 3 hours versus 14 to 18 hours incubation followed by LP PDL irradiation.¹⁷ The mean percent of patient head AK lesions cleared was approximately 90% at the 8-month follow-up, which was comparable to other treatment modalities, such as topical fluorouracil or PDT with blue light.¹⁷ This was the first clinical study to demonstrate that high AK clearance could be achieved with short incubation ALA and without significant side effects. The combination of short incubation topical ALA and LP PDL also been shown to be effective for the treatment of photoaging (Table I).²³

IPL. The term photodynamic photorejuvenation has been applied to the use of IPL in the treatment of AK and photodamage.⁵³ Among all the light sources, IPL combined with ALA PDT has been the most extensively studied for use in photorejuvenation; this largely stems from the fact that IPL has been independently shown to rejuvenate skin while spanning wavelengths that activate the photosensitizer protoporphyrin IX. A randomized, split-face design clinical study comparing ALA IPL to IPL alone demonstrated greater improvement on the ALA side in erythema, dyspigmentation, and fine rhytides following 2 monthly treatments.²⁴ Another IPL following a 1- to 2-hour incubation of topical ALA resulted in crusting when fluences above a certain threshold were delivered.⁵⁴ ALA IPL varies in both clinical response and side effect profile, likely because of the variability of different IPL devices in wavelength irradiances (Table I).

In sum, a variety of light sources may be employed in conjunction with topical ALA for photorejuvenation. Blue light, LP PDL and IPL are the most well established light sources used in PDT for the treatment of photoaging.

Nonablative resurfacing methodology

Patient selection and preoperative management. Patients with mild, moderate, and severe rhytides and photodamage are candidates for

Table I. Photodynamic therapy protocols for photorejuvenation

Application of photosensitizer	Actinic keratosis/photoaging
5-ALA	1-3 hrs
MAL	3 hrs occluded
Laser or light irradiation	
Blue	16'40"
LP PDL	7-7.5 J/cm ² , 10 ms, 10 mm, DCD 30 ms/30 ms, 1 pass AK, acne, 2-3 pass AC, ND for BCC
IPL	Standard photorejuvenation settings, start lowest fluence AK, photoaging, ND for AC and BCC

AC, Actinic cheilitis; AK, actinic keratosis; ALA, aminolevulinic acid; BCC, basal cell carcinoma; DCD, dynamic cooling device; IPL, intense pulsed light; LP PDL, long-pulsed pulsed dye laser; MAL, methylated aminolevulinate; ND, not determined.

nonablative technology; however, patient expectations must be handled directly. Patients who are concerned about risk and recovery and are willing to accept minimal efficacy in exchange for minimal risk are the ideal candidates for nonablative approaches. Dark-skinned and tanned patients should be cautioned of the risk of posttreatment dyspigmentation with the majority of the nonablative laser modalities. A test spot may be performed on a high-risk patient before the first treatment session, and patients should be instructed as to sun avoidance and sunscreen use following treatments. These lasers are avoided in the case of a patient who has received systemic isotretinoin within the preceding 6 months because of the reported increased risk of impaired wound healing in these individuals.⁵⁵ Pregnant women are best not treated until after delivery and breastfeeding because of the pain and discomfort during the procedure as well as an increased risk of hyperpigmentation.⁵⁶ Patients should be queried as to pregnancy and breastfeeding during the consenting process; however, it is not our recommendation to conduct routine pregnancy testing on every female patient. Consider patients with a history of silicone injections with caution, though there has been only one potential adverse event in a patient who had RF skin tightening and developed lumps in the areas where silicone had been previously injected (R. Geronemus, oral communication, 2005) and whereas no untoward effects have been observed in silicone-injected patients receiving RF treatment in the authors' experience. Herpes or bacterial prophylaxis are not routinely prescribed before nonablative resurfacing. However, in patients with a history of recurrent herpes infections or Staphylococcal infections of the facial skin, a course

Table II. Nonablative laser resurfacing systems

Laser type	Wavelength	Fluence	Pulse duration	Spot size (mm)
Vascular				
Pulsed KTP	532	15	20 ms	10
Pulsed dye	585	3	350 microns	5
LP PDL	595	6-8	6 ms	10
Infrared				
Nd:YAG	1064	50	50 ms	12
	1320	18	200 microseconds	6
Diode	1450	8-14	250 ms	6
Erubium glass	1540	up to 126	3.3 ms	4
IPL				
Quantum SR	515-1200	24-28	2.4, 4.0	—
Radiofrequency				
RF, monopolar (Thermacool)	RF current bipolar	61.5-63.5	—	—
RF, bipolar/diode/IPL (Elos, Galaxy, or Elite; Syneron)	RF current bipolar; 900 nm; 590-1200 nm	18-100; 20-30; 20-30	—	—
RF/red light (ST Refirme; Syneron)	RF current bipolar; 590-1200 nm	100-120	—	—
RF, unipolar (Accent; Alma Laser)	RF electromagnetic radiation	50-250	—	—
RF, bipolar (Accent; Alma Laser)	RF current bipolar	40-100	—	—

For abbreviations, see the Abbreviations list at the beginning of this article.

of antiviral and/or bacterial prophylaxis may be prescribed as described later for fractional and ablative resurfacing.

Anesthesia. Pulsed dye, KTP, and IPL treatment are minimally painful and in the authors' experience require no anesthesia. Topical anesthesia is the mainstay for pain control during nonablative resurfacing using the 1320-, 1450-, and 1540-nm devices. A topical anesthetic agent, such as lidocaine and prilocaine cream (EMLA) or 4% to 5% lidocaine (LMX, LMX-5) is applied for 1 hour before the procedure. Cold packs may be applied immediately after laser treatment to alleviate any further discomfort. No discomfort should be expected once the laser treatment is concluded. Treatment with the Thermage device is uncomfortable. Using the new algorithm, treatment discomfort has been lessened, but oral sedation and or intramuscular analgesia makes the procedure completely comfortable. Combination radiofrequency and diode or IPL system (Galaxy or Elite; Syneron, Irvine, Calif) does not require systemic analgesia, because the discomfort is well controlled with topical anesthetic creams. The ST Refirme handpiece to the Syneron device is associated with minimal discomfort and generally does not require anesthetic. The Alma Accent (Alma Laser) is painless and requires no anesthesia.

Technique

The treatment parameters differ greatly among the different laser systems in the nonablative category

(Table II). The vascular lasers, such as the pulsed 532-nm and PDLs are operated at subpurpuric fluences and pulse durations in a minimally overlapping pass (Table II). Multiple treatments numbering roughly 5 are administered every 3 to 4 weeks. The infrared lasers, such as the 1320-nm Nd:YAG and 1450-nm diode are operated at the highest tolerated fluence to insure success. Treatment with insufficient energy produces little if any wrinkle reduction or scar improvement (Table II). To protect the epidermis from thermal injury, these lasers are used in conjunction with a cryogen spray delivered several milliseconds before laser pulsing for epidermal protection. One to three passes may be administered per treatment depending upon the device used. Treatments with these lasers are typically administered in a series of 5 or 6 at 2- to 4-week intervals. The 1320-nm Nd: YAG has an added feature showing the peak skin temperature following each pulse, which allows the clinician to titrate the fluence to achieve a peak skin temperature of approximately 40°C to 42°C, which is correlated with greater clinical improvement. Erythema and minimal edema is the desired clinical endpoint regardless of laser system used, and also appears to be directly correlated with clinical outcome. A minimum of 4 treatments is required before improvement is seen. Patient education in advance of a series of treatments is essential to patient satisfaction. IPL devices differ dramatically between systems; however, all require the application of cold aqueous gel and one to multiple passes

in each treatment session. A series of 5 to 6 or more treatments are typically used.

RF treatment techniques vary depending on the device being used. The patient is grounded using a grounding pad for monopolar RF; for bipolar RF and the novel unipolar RF system, this is not necessary. A coupling fluid or aqueous gel is used with the treatment tips of the devices. Recently, the parameters for the Thermage device have been optimized to include low fluences and multiple passes.⁴² Combination RF and diode or IPL (Polaris and Aurora or Galaxy; Syneron) require the application of aqueous gel and multiple passes in each treatment session until the clinical endpoint of erythema and minimal edema is achieved.⁴⁵ The Accent (Alma Laser) employs mineral oil to reduce friction, and the mobile handpiece is moved rapidly over the area until the target temperature of 40°C to 43°C is attained and maintained for several successive passes.^{47,48}

Postoperative management. The advantage of virtually all nonablative devices and techniques is that postoperative care is unnecessary. Immediately postoperatively, minimal erythema and edema resolves within several hours. The majority of patients can apply makeup and return to normal daily life immediately following treatment. Blistering, transient hyperpigmentation, and pinpoint scarring have been reported with the original 1320-nm device.⁵⁷ Dramatic improvements have been made in this device, which has increased the degree of improvement at the same time as reducing the risks of side effects. In the authors' experience, vesiculation occurs with increased frequency in patients with a history of flushing and rosacea, and may be prevented by premedication with antihistamines (H₁ blockers). In the event of vesiculation, the patient is advised to apply a petrolatum-based ointment twice daily until healed. These vesicles heal without scarring in the vast majority of cases.

FRACTIONAL RESURFACING Fractional resurfacing systems

The newest technology to enter the laser arena is fractional resurfacing (Table III) or fractional photothermolysis, a term coined by Rox Anderson, MD, and the Reliant Technologies (Mountain View, Calif).⁵⁸ The concept behind this approach is to thermally alter a fraction of the skin, leaving intervening areas of normal skin untouched, which rapidly repopulate the ablated columns of tissue. The 1550-nm erbium-doped mid-infrared fiber laser induces cylindrical areas of thermal damage to the epidermis and upper dermis spaced at 2000 microscopic treatment zones of photothermolysis per cm².

Table III. Fractional resurfacing with 1550 nm erbium fiber laser

Indication	Energy (mJ)	Density (MTZ/cm ²)	No. of passes	Total treatment density (MTZ/cm ²)
Melasma				
Phototypes I-II	6	250	12	3000
Phototypes III-VI	6	250	8	2000
Rhytides				
Mild	12	125	12	1500
Moderate	15	125	8	1000
Severe	20	125	8	1000
	12	125	16	2000
Acne scarring				
Phototypes I-II	15-20	125	8-12	1500-1000
Phototypes III-VI	15	125	8	1000
Photoaging				
Phototypes I-II	10	250	8	2000
Phototypes III-VI	8	250	8	2000

MTZ, Microthermal zone.

Each column is approximately 70 to 150 microns in width and induces vertical thermal injury of 400 to 700 microns in depth into the dermis, referred to as "micro thermal zones." These zones comprise approximately 15% to 25% of the skin surface area per treatment session. Similar to ablative laser resurfacing, the areas of thermally ablated tissue are repopulated by fibroblast activity of neocollagenesis and epidermal stem cell reproduction. As compared to ablative resurfacing, fractional resurfacing results in faster recovery and fewer side effects.⁵⁸ Although erythema and edema resolve within a few days in most patients, the improvement in rhytides and photodamage is not as impressive as with ablative resurfacing. Mild to moderate improvement is observed, requiring multiple treatment sessions, totaling 5 to 6 and spaced at 1- to 4-week intervals. Sun-induced pigmentary alteration improves more quickly, while wrinkles require more treatments to see significant improvement. Early findings have demonstrated moderate improvement in rhytides and dyspigmentation in the majority of patients. Pigmentary improvement is similar to that seen with pigment specific Q-switched lasers and IPL photorejuvenation, but acne scars and wrinkles appear to improve faster and to a greater extent than with the other nonablative techniques, as shown in Figure 3.

The original Fraxel SR (Reliant Technologies) was the aforementioned 1550-nm erbium fiber laser which was approved for use at 40 J/cm² by the FDA in 2003 for soft tissue coagulation, periorbital rhytides and pigmented lesions in 2004, and skin resurfacing and melasma and acne and surgical

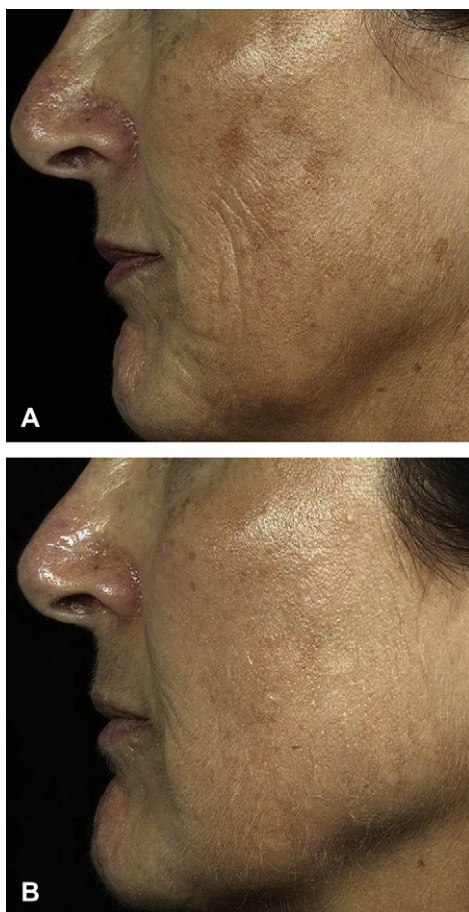


Fig 3. Fractional resurfacing. Patient before (A) and after (B) treatment with 1550-nm erbium-doped mid-infrared fractional laser resurfacing. (Courtesy of Zakia Raman, MD.)

scarring in 2006. The new addition is the Fraxel SR1500, which was approved by the FDA in January 2007 at 70 mJ/cm².⁵⁹ This dose allows for greater penetration depth (up to 1.4 mm) as compared to the 300- to 800-micron depth attained previously, and is aimed at treating deeper rhytides. In addition, the Fraxel AFR, a fractionated CO₂ laser that provides a deeper penetration depth, is currently in development.⁵⁹

Competitors in fractional resurfacing include the Lux 1540 Fractional (Palomar Medical Technologies, Burlington, Mass), a 1540-nm pulsed device which is approved by the FDA for soft tissue coagulation.⁵⁹ This device contains a handpiece that divides pulsed light into microbeams which penetrate up to 1 mm. The advantages of the Palomar system include the practicality and versatility of a handpiece that attaches to its pulsed light and laser system and the fact that it is painless. Another version of fractional resurfacing by the same manufacturer is a noncoherent infrared light source, which generates pulses of light in the 825 to 1350 nm range of the spectrum

(LuxIR Fractional infrared handpiece attachment for the StarLux pulsed light and laser system). This technology delivers an array of small beams that create a periodic lattice of isolated hyperthermic columns ranging from 1.5 to 3.0 mm in diameter to the reticular dermis. Finally, a Lux2940 fractional laser handpiece has been added, using delivery of erbium laser light to deliver very deep ablative columns.

Another fractional resurfacing device is the Affirm laser (Cynosure Inc, Westford, Mass), which sequentially emits 1320-nm and 1440-nm wavelengths at fixed intervals. A microlens array is employed to diffuse the laser light into a lattice of microbeams, with targeting of superficial and deeper penetration depths through the two wavelengths. Finally, a fractional CO₂ with versatile settings is also under investigation (Mixto, DEKA). Published, peer-reviewed data are pending for these newer fractional resurfacing modalities.

Fractional resurfacing methods

Patient selection and preoperative management. Patients with dyspigmentation and lentigenes require 2 to 3 treatments, whereas those with significant rhytides require at least 5 or more treatment sessions. Patients with melasma require multiple treatments, and long-term follow-up is needed to properly assess how effective this treatment is for a recalcitrant condition that has a high recurrence rate with other modalities. Given the report of hypertrophic scarring following ablative resurfacing in a patient with a history of recent isotretinoin use, we currently recommend a 12-month waiting period following discontinuation of isotretinoin before commencing fractional resurfacing.⁵⁵ All patients, regardless of whether they have a history of herpes labialis, receive prophylactic oral antivirals, such as acyclovir, famciclovir, or valacyclovir, starting 1 day before fractional resurfacing and continuing for 5 days postoperatively or until reepithelialization is complete. Oral antibiotics, such as dicloxacillin or azithromycin, may be prescribed to patients with a history of bacterial infections of the facial skin to reduce the chance of secondary bacterial infection.

Anesthesia. Topical anesthesia is required, typically involving the application EMLA or LMX cream for 60 minutes before the procedure. During the procedure, cold air cooling (Zimmer MedizinSystems, Irvine, Calif) is required to minimize discomfort. Some of the newer fractional resurfacing devices are reportedly painless.

Technique. Dry gauze is used to remove the anesthetic cream and a blue dye applied (original Fraxel protocol) in order to optimize contrast for the optical scanner, which is a component of the device. Newer versions of the Fraxel device (and newer

fractional resurfacing devices) do not require blue dye application. A thick layer of gel is then reapplied and treatment begins. The standard treatment parameters employ 8-10 mJ/Fraxel and a Fraxel density of 250/cm². The treatment time is approximately 20 to 30 minutes to treat the entire face. Approximately 8 passes are conducted over each treatment area, to generate a total Fraxel density of 2000/cm². The face is cleaned with soap and water and moisturizer applied.

Postoperative management. Some advocate the administration of oral prednisone 30 mg the morning of the procedure and an additional dose the subsequent two mornings following the procedure if edema persists.

ABLATIVE LASER RESURFACING

Ablative laser systems

Continuous wave (CW) CO₂ lasers were used in the 1980s and 1990s to resurface photodamaged skin. Although highly effective, the risk of unwanted side effects was high, with unwanted thermal damage and scarring. For laser skin resurfacing (LSR) to be effective and safe, selective thermal destruction based on the principles of selective photothermolysis is required.⁶⁰ The chromophore as described below is water. In order to control the depth of thermal damage that occurs in tissue, the appropriate pulse duration needs to be less than 1 millisecond, and in order to achieve tissue vaporization, sufficient energy must be delivered within this time. The development of short-pulse, high-peak power, rapidly scanned CW CO₂ and normal mode Er:YAG lasers provided the ability to accurately thermally ablate controlled layers of tissue.

CO₂ laser

The CO₂ laser emits a 10,600-nm wavelength, which is strongly absorbed by tissue water (absorption coefficient, 800 cm⁻¹). The penetration depth is dependent upon the water content and independent from either melanin or hemoglobin. With a pulse duration of less than 1 millisecond, CO₂ laser light penetrates approximately 20 to 30 μm into tissue, and residual thermal damage (RTD) can be confined to a thin layer of 100 to 150 μm of tissue, although thermal coagulation up to 1 mm has been reported.⁶¹ The vaporization or boiling point of water at 1 atmosphere is 100°C. Further calculations reveal that the necessary fluence to achieve pulsed-laser ablation of skin tissue is 5 J/cm², with less energy producing diffuse tissue heating without vaporization.⁶² During ablation at these parameters, the skin temperature reaches approximately 120°C to 200°C. The beam diameter plays a role, with small beams of

100 to 300 μm in diameter achieving high fluences and rapid tissue vaporization; however, if the beam is not moved rapidly across the skin surface, desiccation, charring, and diffusion of heat may occur. Larger beam sizes of greater than 2 mm induce nonvaporization heating and increase the risk of deep thermal damage because of the need to apply low fluences for longer periods of time in order for visible vaporization to occur. Based on these findings, the high-pulsed or scanned CO₂ lasers evolved in order to precisely control the depth of ablation and thermal damage by combining high peak powers with short pulses and rapid movement across the skin surface.

Two basic CO₂ laser systems have been used in cutaneous resurfacing (Table IV). The first type is the high-powered pulsed CO₂ laser system, which delivers energy in individual pulses of about 1 millisecond or less (UltraPulse; Lumenis, Santa Clara, Calif). This laser produces up to 500 mJ of energy in each individual 600 μs⁻¹ pulse. Vaporization can be performed either with a 3-mm spot size or by a computer pattern generator (CPG), which can deliver various patterns of up to 80 pulses, each pulse measuring 2.25 mm in diameter. The second type of CO₂ resurfacing laser achieves well controlled tissue ablation by rapidly scanning the focal spot of a focused CW CO₂ laser over the skin. The Sharplan SilkTouch and FeatherTouch flash scanners (Lumenis) are examples of computer-driven mechanical devices that scan a 0.2-mm spot in a spiral manner ranging in diameter from 8 to 16 mm in several shapes at a constant velocity. No individual spot is irradiated more than once, and the dwell time on any individual spot is less than 1 millisecond, thus achieving fluences above the ablation threshold. Despite these technical differences, the two laser systems accomplish similar clinical results.⁶³ In general, 2 passes with the SilkTouch are approximately equal to 3 pulses with the UltraPulse and 4 passes with the FeatherTouch in terms of the amount of tissue removed and the depth of RTD. Since the development of the UltraPulse and the SilkTouch laser systems, other devices using similar parameters have been developed, with preliminary results suggesting clinical results equivalent to the prototype lasers.⁶⁴ The main differences are in the specific parameters used with each laser system.

The aforementioned CO₂ laser systems appear to be comparable in efficacy, while techniques with each laser vary greatly. Most reports have shown significant improvement of photoaged skin regardless of laser system used. Most patients with wrinkles attain a 50% to 90% improvement.^{65,66} Optical profilometry has been utilized to objectively quantify

Table IV. Ablative resurfacing

Type	Wavelength	Beam delivery	Power	Pulse duration	Energy	Energy fluence	Spot size
CO ₂	10,600	Individual pulses	500 W peak power, pulsed	<950 μ sec	50-500 mJ/pulse	5-7 J/cm ²	3-mm collimated or CPG
	10,600	Spiral or rasterized scan	7-100 W average power, scanned CW beam	0.03-0.52-sec scan duration 300-1000 μ s dwell time	Not applicable; CW laser	5-15 J/cm ²	0.6- to 15-mm scan size with 0.1- to 0.25-mm focused beam
Er:YAG	2940	Individual pulses	10-20 W average power	300 μ sec-10 ms	0.1-3.0 J/pulse	1-50 mJ/cm ²	2- to 7-mm collimated or focused; pattern generator

wrinkle improvement.⁶⁷ The improvement is usually more marked for fine wrinkles, especially those around the eyes or mouth, and less pronounced for deeper rhytides and creases. An example is shown of a patient before (Fig 4, A) and following (Fig 4, B) treatment with CO₂ laser resurfacing.

CO₂ laser treatment of acne scars has been moderately effective. Severe acne scars are less responsive than mild to moderate acne scars. One investigator reported 81.4% improvement in moderate atrophic scars,⁶⁸ while another found adequate improvement in only 2 of 4 patients with severe acne scarring.⁶⁹

Er:YAG laser

The Er:YAG laser was the next ablative laser developed for skin resurfacing (Table IV). It emits a wavelength of 2940 nm in the infrared range, which is close to the absorption peak of water and yields an absorption coefficient 16 times that of the CO₂ laser. The Er:YAG laser's penetration depth is limited to about 1 to 3 μ m of tissue per J/cm² versus the 20 to 30 μ m observed with the CO₂ laser.⁷⁰ This provides a more precise ablation of skin with minimal thermal damage to the surrounding tissues; the estimated RTD is 10 to 40 μ m. Operating the Er:YAG laser at a fluence of 5 J/cm² vaporizes the epidermis in 4 passes, 8 to 12 J/cm² achieves this after 2 passes.

The overall efficacy of the Er:YAG laser is comparable to the CO₂ laser; however, the CO₂ laser is still considered superior in most comparative studies. Er:YAG laser has been associated with less tissue tightening or contraction as compared to the CO₂ laser, which may impact the long-term outcome in photoaged skin.⁷¹ The variable-pulsed Er:YAG laser, with pulse durations ranging from 10 to 50 milliseconds, demonstrates immediate tissue contraction and a healing rate that is intermediate between the short-pulsed Er:YAG with pulse durations of 250 to 350 microseconds and CO₂ lasers.⁷² In comparative studies, the variable-pulse Er:YAG laser was very effective in the removal of rhytides, although the CO₂ laser was still found to be slightly more efficacious.⁷³⁻⁷⁵

The Er:YAG laser results in less severe side effects of discomfort, erythema, and edema, and overall healing times are faster than the CO₂ laser.⁶² When compared to the depth of ablation performed, healing times between the two lasers have been similar.⁷⁶ In contrast, CO₂ laser treatment is bloodless, because of its ability to photocoagulate blood vessels less than 0.5 mm in diameter, whereas bleeding increases with successive passes with the Er:YAG laser.

Histologic changes observed following ablative resurfacing with CO₂ and Er:YAG both demonstrate

neocollagenesis approximately 6 weeks postoperatively. Early on, however, the inflammatory cell infiltrates differ: lichenoid polymorphonuclear cell infiltrate following CO₂, as opposed to a mild perivascular polymorphonuclear and eosinophil infiltrate following Er:YAG. Recently, the genetic and histochemical changes following CO₂ resurfacing have been evaluated. Reverse-transcriptase polymerase chain reaction and immunohistochemistry evaluations of the facial skin of 28 patients following resurfacing demonstrated up regulation of procollagens I and II, interleukin 1- β , TNF- α , TGF- β 1, and matrix metalloproteinases (MMPs)-1, -3, -9 and -13.⁷⁷

Plasma skin resurfacing. A novel device for performing ablative resurfacing has been developed which works by passing radiofrequency into nitrogen gas. The “nitrogen plasma” causes rapid heating of the skin with limited tissue ablation and minimal collateral thermal damage. Several reports indicate improvement in facial rhytides and scars following treatment. Epidermal regeneration occurs by 7 days postoperatively with neocollagenesis visible on histologic analysis at 90 days.⁷⁸ Comparative studies are needed to evaluate the safety and efficacy of this device as compared to CO₂ and Er:YAG laser resurfacing. Results appear to be similar to gentle CO₂ and Er:YAG laser resurfacing. The more aggressive the treatment—that is, the higher the fluence—the more impressive the results. Just where plasma resurfacing fits in the spectrum of resurfacing devices, however, remains to be seen.

Indications for ablative laser resurfacing

Laser skin resurfacing has been employed to treat a large number of skin conditions, but the two most common indications are photoaging and scarring. Photoaging, which may be defined based on the criteria of rhytides, dyspigmentation, vascularity, elastosis, and AKs, is highly responsive to laser resurfacing. Of import, perioral and periorbital rhytides, which are resistant to face lift procedures, are highly amenable to laser resurfacing. Fine rhytides, particularly in the periorbital, perioral, and cheek areas may be completely eradicated with laser resurfacing; deeper creases are also improved, probably secondary to a general tightening effect. Rhytides and creases upon active movement and facial expression, such as in the glabella and nasolabial folds, tend to be more resistant to laser resurfacing.

As discussed earlier, laser resurfacing is effective for scars, including acne, traumatic, and surgical scars. It is most effective for elevated or modestly deep distensible acne scars, in which the fibrotic tissue can be removed or the shoulders of the scars

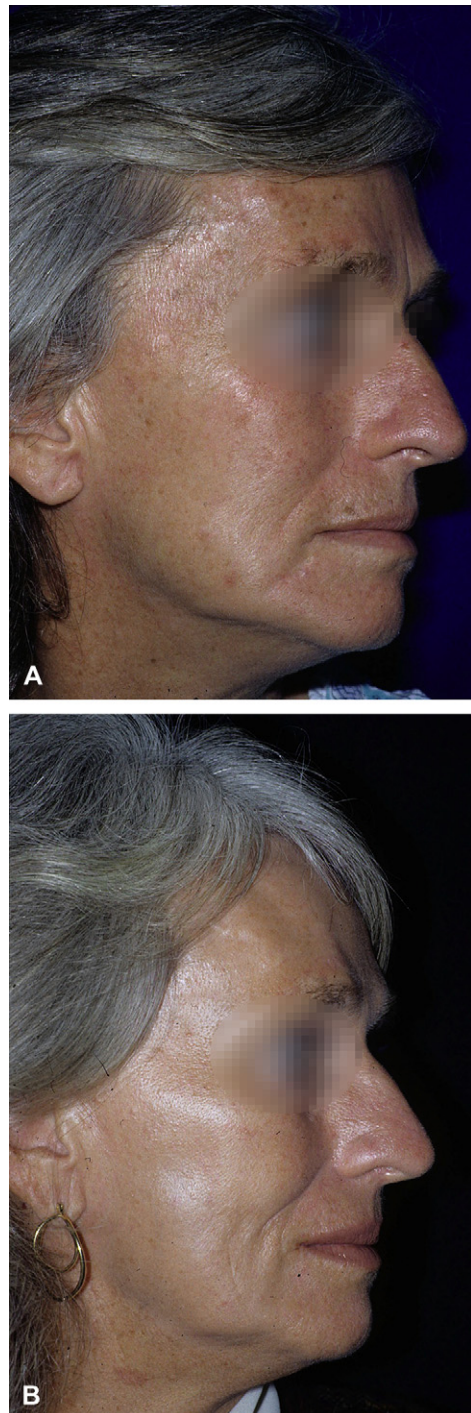


Fig 4. Ablative laser resurfacing with CO₂ laser. Patient before (A) and after (B) CO₂ laser resurfacing. (Courtesy Jeff Dover, MD.)

can be ablated and “sculpted.” Ice-picked or bound-down scars are less responsive, requiring a combined approach of subcision and punch excision/grafting followed by laser resurfacing 6 to 8 weeks later.⁷⁹ Varicella scars may be improved with spot laser resurfacing, with fresh scars (6 to 10 weeks

after varicella) responding more completely compared to older scars. Postsurgical and traumatic scars may achieve dramatic improvement, especially if resurfaced 6 to 10 weeks after the surgery or injury. Resurfacing well-vascularized wound edges immediately after surgery and before suture placement may also improve cosmetic outcome. Improvement in acne scars is generally observed over a 3-month course, but may improve further to up to 1 year following ablative resurfacing.

Because laser resurfacing is relatively bloodless and allows for controlled tissue removal with a low risk of scarring, it has been used to treat rhinophyma,^{80,81} diffuse AC,⁸² AKs, benign hamartomas, and other lesions.

Ablative resurfacing methods

Patient selection. Patients of any age and in good health are candidates for laser resurfacing. The optimal candidate is a patient with Fitzpatrick skin types I to IV with photodamage and moderate postoperative expectations. Contraindications to the procedure include a history of keloids or connective tissue diseases. Dermatologic conditions which result in a reduction in adnexal structures, such as history of radiation therapy or scleroderma, should also serve as contraindications because of the absence of stem cells in the appendageal bulge, which reduces reepithelialization postoperatively. Diseases with koebnerizing features, such as psoriasis or vitiligo, are considered relative contraindications. Previous isotretinoin therapy has been associated with atypical scarring after dermabrasion or chemical peeling, even if the procedure was performed more than 1 year after isotretinoin treatment.⁵⁵ Although there is no sound scientific recommendation for the length of time required after isotretinoin treatment to proceed with laser resurfacing, it is generally recommended that patients should wait for 1 year before undergoing the procedure. Resurfacing performed at the same time or soon after face lifting or blepharoplasty increases the risk of skin necrosis and scarring, because of the altered blood circulation of the undermined skin following these procedures.⁸³ Thus, laser resurfacing of undermined skin should be performed at least 6 months after the original surgical procedure. Certain anatomic locations are associated with an unacceptably high risk of scarring, such as the hands, neck, and chest.

Preoperative course. Preoperative regimens used to improve outcome from laser resurfacing include the use of tretinoin, which appears to speed reepithelialization after dermabrasion and chemical peels, and it may work similarly in laser resurfacing.⁸⁴ Patients with Fitzpatrick skin type III or darker

pigmented skin types are not usually started on topical bleaching agents, such as hydroquinone, before resurfacing, because they have never been shown to reduce the risk of postinflammatory hyperpigmentation. All patients, regardless of whether they have a history of herpes labialis, receive prophylactic oral antivirals, such as acyclovir, famciclovir, or valacyclovir, starting 1 day before resurfacing and continuing for 10 days postoperatively or until reepithelialization is complete. Oral antibiotics, such as dicloxacillin or azithromycin, are also routinely prescribed to reduce the chance of secondary bacterial infection. Some physicians recommend a dose of fluconazole on the day of resurfacing to reduce the risk of *Candida* infection in the treated area,⁸⁵ but given the very low risk of yeast infection, we do not recommend its use. In addition, a 3- to 4-day course of systemic corticosteroids preoperatively is occasionally prescribed to reduce the significant edema that usually occurs during the first 72 hours after the procedure, but again, we do not recommend this.

Anesthesia

The CO₂ laser typically produces more discomfort than the Er:YAG laser, presumably because of its tissue heating effect that may stimulate type C pain fibers at the dermoepidermal junction. For localized treatment of individual cosmetic units, such as the periorbital and/or perioral areas, local anesthesia is sufficient. Topical anesthetic agents, such as lidocaine and prilocaine cream (EMLA cream) are used for superficial laser procedures, namely the short-pulsed Er:YAG laser, which is generally less painful than the CO₂ laser. Topical anesthetics can be used either alone or, more commonly, as supplemental agents to local or regional anesthesia. Nerve blocks using lidocaine 1% to 2% with 1:100,000 or 1:200,000 epinephrine are effective in anesthetizing the central portions of the face, such as the central forehead, the median cheek/nose and upper lip, and the lower lip and chin. Sensory blockades of the lateral surfaces of the face are difficult to perform. In these areas, local infiltration with a mixture of 2% lidocaine and 1:100,000 epinephrine, bupivacaine 0.5%, 1:10 NaHCO₃ 8.4%, and hyaluronidase 75U is effective. The HCO₃ neutralizes the pH of the mixture and decreases the pain during the injection, while the hyaluronidase improves tissue diffusion.

For full-face laser resurfacing, a combination of topical and systemic agents is usually employed. Regimens typically include a combination of intramuscular sedation in addition to nerve blocks plus topical or injectable anesthetics; inhalation anesthetic; and total intravenous anesthesia combining

propofol, an anxiolytic narcotic (fentanyl), and a laryngeal mask adapter (LMA). The latter has become the anesthetic of choice for office-based CO₂ resurfacing.

Technique

In CO₂ laser resurfacing for rhytides, a first "pass" of nonoverlapping and vaporizing laser pulses is performed, followed by gentle yet thorough wiping of the desiccated debris with saline-soaked sponges. The skin surface then reveals a pink hue, representing partially denatured papillary dermis. Dry gauze is used to remove any water remaining on the skin, which may absorb laser energy and block its targeting of dermal tissue. A second laser pass is then performed, and subsequent passes result in progressive yellowing and visible tissue contraction. Fine papillation may appear, representing exposure of pilosebaceous units and acrosyringium. In a typical resurfacing session, 2 passes are made over the entire treated area. Subsequent passes are concentrated on high points of scars or shoulders of rhytides. In order to blend or soften lines of demarcation, the feathering of borders is performed with low-pulse energy and density. The end point of treatment is the effacement of tissue irregularities and visible wrinkles. If yellow or brown discoloration is observed after wiping, then no additional passes should be performed, because this is considered a definite sign of increased thermal necrosis or charring. A single pass of short-pulsed Er:YAG laser may be applied to the face at the conclusion of the CO₂ laser passes in order to decrease reepithelialization time by reducing the thickness of the thermally coagulated tissue without interfering with cosmetic outcome.

In Er:YAG laser resurfacing, less tissue is removed per laser pass. Depending on fluences used, up to 4 passes are required to remove the epidermis, and as many as 8 to 10 passes are needed to reach the desired endpoint, which is the effacement of rhytides or pinpoint bleeding. Visible wound contraction seldom occurs with the short-pulsed Er:YAG laser. It is routinely seen with the variable-pulsed devices. Er:YAG laser resurfacing can be performed either freehand or with a scanner. The treatment field is covered with moderately overlapping pulses using spot sizes of 3 to 7 mm or a pattern generator. Although wiping in between passes is not necessary, it is advisable to wipe away the proteinaceous material at least after the first pass. It is also important not to wipe after the last pass, because it removes the layer of RTD and may result in postoperative bleeding.

In treating acne scars, deeper thermal injury is necessary to effectively improve the scars. Ablation

of the edges of the scars before resurfacing the remainder of the face is recommended, because the lesions may become less conspicuous during the procedure because of facial swelling. In individuals with light pigmentation, the treatment of individual scars without resurfacing an entire cosmetic unit may be performed. Most physicians prefer to treat the entire face or at least a cosmetic unit in order to avoid a visible demarcation between the treated and untreated areas.

Exophytic lesions, such as warts, rhinophyma, or adnexal tumors, may be treated with either the CO₂ or the erbium laser, the end point of treatment being the gross disappearance of the lesions.

Because healing after Er:YAG laser resurfacing is faster than CO₂ resurfacing, combination treatment is sometimes performed to achieve the benefits of both lasers. Generally, the CO₂ laser is used first, followed by 1 to 2 passes of an Er:YAG laser at 5 to 10 J/cm² to remove some degree of the thermal damage left behind by the CO₂ laser. Patients undergoing this procedure appear to achieve reepithelialization more quickly, with less postoperative erythema.⁸⁶ Alternatively, the newer variable pulse Er:YAG laser may be employed in the long-pulsed mode to efficiently remove the epidermis and induce collagen tightening, followed by the short-pulsed mode for purely ablative functions (ie, sculpting any tissue irregularities).

Postoperative course

Edema, exudation, and sloughing of thermally denatured collagen occur during the first 1 to 3 days. Edema is often most severe on the second and third postoperative days and treated with ice packs, head elevation at night, and, if severe, oral corticosteroids. Cool compresses are used and wet debridement is performed throughout the first week. Continued 0.25% acetic acid, normal saline, or cool tap water soaks are followed by the application of petroleum jelly or healing ointment. The application of bio-occlusive dressings during the first 24 to 72 hours has been shown to speed reepithelialization after dermabrasion and skin resurfacing. In addition, such dressings have improved patient comfort postoperatively.⁸⁷ Although a low risk of infection has been cited as a potential advantage of such dressings, one study suggested that prolonged use of occlusive dressings was associated with an increased risk of *Pseudomonas* infection. Reepithelialization occurs over 3 to 10 days, depending upon the number of laser passes, and decreases if the skin has been resurfaced with the Er:YAG laser. Topical antibiotics such as bacitracin or bacitracin-polymyxin B are not routinely prescribed because of the high incidence

of allergic contact dermatitis associated with their use. Prophylactic antibiotics against Gram-positive bacteria are continued for a minimum of 5 days postoperatively and oral antivirals are continued until reepithelialization is complete (10-14 days). Acetaminophen (paracetamol) with or without codeine phosphate or hydrocodone can alleviate discomfort. During the first few weeks after resurfacing, patients will often complain of pruritus, which is usually self-limited and controlled by antihistamines and mild topical corticosteroids. There is also evidence that exogenous intake of estrogens improves outcome following ablative resurfacing.⁸⁸

After reepithelialization, there is a variable period of erythema ranging from 1 to 4 months, which is easily camouflaged with a make-up containing green foundation. Sun avoidance after laser resurfacing for the entire period of post-laser erythema should be stressed to the patient to reduce the risk of post-inflammatory hyperpigmentation. As with most cosmetic procedures, patient expectations are the most important determinant of patient satisfaction with the outcome. In general, rhytides and photodamage are the expected areas of improvement, with perioral and periorbital regions responding best. Areas of active creasing caused by muscular movement, such as glabellar or forehead creases, are at best softened. A study evaluated the long-term results of laser skin resurfacing in both the treatment of photodamage and also acne scarring.⁸⁹ One day after LSR, 10 patients (37%) were concerned about the outcome, and 3 (11%) considered it a "terrible" experience. At 2.7 days after the procedure, 23 patients (85%) would recommend LSR, and after 3.7 days, 24 (89%) would have the procedure again. At 3 months, the patients' mean rating of appearance was 2.3 (0-3 scale), and all 27 (100%) felt that their appearance had been improved by LSR. After 30 months, 18 patients (75%) would recommend the procedure, 17 (71%) would have LSR again, 21 (88%) felt that their appearance was improved, and final appearance was rated 1.8 (0-3 scale). Patients undergoing LSR to treat acne scarring were as satisfied as patients treated for photodamage.⁸⁹ Some physicians perform adjunctive botulinum toxin injections during the postoperative phase in order to decrease the theoretical risk of recurrence of rhytides or creases.

Side effects and complications

Side effects following CO₂ laser resurfacing are frequent and predictable. As the ablative technologies and protocols have evolved, complications have become uncommon and preventable if careful technique and postoperative management are followed. Side effects may be categorized as follows:

immediate, predictable effects; infectious; eczematous; follicular; scarring; and pigmentary changes.

Erythema. Erythema persisting for an average of 1 to 4 months is an expected part of the normal healing process. It results from increased blood flow secondary to the laser-induced inflammatory response, the reduced melanin absorption of light, and reduced dermal optical scattering. The erythema usually lasts approximately 1 month for Er:YAG and 2 months for CO₂ laser resurfacing, although persistent erythema lasting up to 12 months posttreatment may occur. Flushing within the treated site with exertion or emotional upset may occur frequently for up to 1 year after resurfacing.

Dyspigmentation. The risk of pigmentary alteration is correlated with the depth of laser damage. Injury extending into the papillary dermis is more likely to cause postinflammatory hyperpigmentation, depending upon the patient's skin type. With deeper passes, hypopigmentation may occur. Postinflammatory hyperpigmentation is the most common adverse effect of laser resurfacing, occurring in up to 36% of patients and most commonly in Fitzpatrick's skin types III to VI.⁹⁰ It is more common during the summer months and year-round in sunny areas. At the first sign of hyperpigmentation, hydroquinone and tretinoin are prescribed and sun exposure is avoided. Under these circumstances, the hyperpigmentation usually resolves within a few months. Rates of hyperpigmentation as low as 2.8% have been reported among patients who have been pretreated with bleaching creams and retinoic acid.⁹¹

Two types of hypopigmentation secondary to laser resurfacing have been reported. One is relative hypopigmentation of the resurfaced skin as compared to the background untreated, photodamaged skin with its characteristic mottled discoloration.⁹² This mismatch can be minimized by resurfacing the entire face or at least entire cosmetic units and by feathering the treatment into the surrounding areas. A medium-depth chemical peeling of the untreated areas may also be attempted to even the skin coloration. The other type of hypopigmentation is a delayed hypopigmentation, which develops 6 to 12 months after resurfacing and has been reported in 16% of patients. In these patients, there appears to be a return to their normal constitutive pigmentation 2 months after resurfacing, followed by an unexplained delayed loss of pigmentation.³ The rates of hypopigmentation in our practice are lower than reported rates, though a formal study of the newer modalities and protocols has not been published.

Acneiform eruptions. Milia may result from follicular reepithelialization compounded by the

use of occlusive moisturizers. Acne is a frequent postoperative event, especially in patients with a past history of acne. It usually develops in the first few weeks after resurfacing and responds to standard acne treatments. Isotretinoin should be avoided in the postoperative period because of the possibility of hypertrophic scarring.

Eczematous dermatitis. Contact dermatitis, observed following the use of some topical anesthetics, does not correspond with patch test findings but resolves with appropriate treatment.³ This occurrence increases the chances of postoperative erythema and hyperpigmentation. Eczematous dermatitis may develop during the first 4 weeks after treatment and responds to emollients and topical mid-potency corticosteroids. Perioral dermatitis is infrequently observed 1 to 3 months after resurfacing of the perioral region. It is best treated with a course of oral doxycycline and is usually self-limited.

Infections. Infection is of primary concern because of the removal of the epidermis and part of the dermis during laser resurfacing. The risk of bacterial infections is minimized with prophylactic use of systemic antibiotics and appropriate topical care. Infections with *Staphylococcus aureus* or *Pseudomonas aeruginosa* may occur during or after the prophylactic course, presenting as pustules or yellow crusting, patchy erythema, or delayed healing with pain or pruritus. In these cases, broad antibiotic coverage should be instituted while awaiting the microbiology cultures. Antiviral chemoprophylaxis was originally confined to those with a history of herpes simplex infection, but results suggest that subjects with no past history of infection frequently develop herpes simplex activation in treated areas.⁹³ It is now standard practice to use antiviral prophylaxis in all patients undergoing laser resurfacing. Yeast infections, especially candidiasis, may also occur post-resurfacing, but they respond well to treatment with systemic antifungals. Some administer antifungal prophylaxis in all patients.

Scarring. The risk of scarring from laser resurfacing is small and further minimized by proper patient selection and a conservative approach regarding the number of laser passes, followed by careful wound care. Scarring occurs following a large number of passes, excessive energy fluences, or pulse stacking (overlap of laser irradiated sites, especially after the first pass), which causes excessive thermal damage.⁹⁴ It is preferable to perform a touch-up procedure in the future rather than resurface too deeply with the initial treatment. Any areas that develop scar tissue should be promptly treated with topical and intralesional corticosteroids, silastic gel sheeting, and PDL treatment.

Quantitative analysis of laser resurfacing

Until recently, studies of laser resurfacing have relied largely on subjective assessments of patients or patient photographs, resulting in a highly variable and unreliable measure of efficacy. In order to assist in a more quantitative analysis of patients and pre- and posttreatment photographs, wrinkle classification systems have been developed. Initially designed to assess global improvements seen with ablative laser resurfacing, most recently a comprehensive grading system has been devised that allows for the independent, quantitative assessment of individual categories of skin aging.

Prior global classification schemes. A decade ago, grading scales were devised to assess clinical outcome from ablative technologies, grouping the various aspects of skin aging into broad but useful classification schemes.^{65,95} The most widely used scales were the Glogau and Fitzpatrick wrinkle assessment scales.^{65,95} These well-accepted grading scales were primarily developed to evaluate ablative technologies, such as chemical peeling or carbon dioxide laser resurfacing, which yield global improvement in all aspects of skin aging. A disadvantage of these scales is that they were not intended to independently assess each individual category of aging skin, but rather to group findings together into stages of severity.

Since those scales were first devised a decade ago, nonablative and fractionally ablative technologies have emerged and quickly evolved. Nonablative laser resurfacing technologies typically target specific aspects of skin aging, but not all, making broad groupings of clinical findings less useful in assessing their efficacy.⁹⁶ For example, RF targets skin laxity but not lentigines or telangiectasiae, whereas IPL targets pigment and vascularity with little effect on rhytides. In addition, patients seeking nonablative treatments often do not fall neatly into any one global category, displaying certain aspects of skin aging but not others—for example, dyspigmentation in the absence of significant laxity or rhytides. By not separating the various facets of skin aging from each other, but rather placing them into broad groups, the Glogau and Fitzpatrick schemes are less easily applied to assessing efficacy of nonablative modalities. Thus, a comprehensive grading scale should be applied that individually grades the multiple, distinct categories of skin aging, allowing for quantitative assessment of nonablative and other modalities that target individual aspects of the aging skin.

Current comprehensive grading scale. A comprehensive grading scale, shown in Table V, separates the individual categories of skin aging and allows for quantitative analysis of changes within

Table V. Comprehensive grading scale of rhytides, laxity, and photodamage⁹⁶

Grading scale	Descriptive parameter	Categories of skin aging and photodamage							Overall score	Patient satisfaction (Y/N)
		Rhytides	Laxity	Elastosis	Dyschromia	Erythema telangiectasia	Keratoses	Texture		
0	None	None	None	None	None	None	None	None	None	
1	Mild	Wrinkles in motion, few, superficial	Localized to NL folds	Early, minimal yellow hue	Few (1-3) discrete small (<5 mm) lentigines	Pink E or few T, localized to single site	Few	None	Subtle irregularity	
1.5	Mild	Wrinkles in motion, multiple, superficial	Localized, NL and early ML folds	Yellow hue or early, localized PO EB	Several (3-6), discrete small lentigines	Pink E or several T localized to 2 sites	Several	Mild irregularity in few areas		
2	Moderate	Wrinkles at rest, few, localized, superficial	Localized, NL/ML folds, early jowels, early submental/SM	Yellow hue, localized PO EB	Multiple (7-10), small lentigines	Red E or multiple T localized to 2 sites	Multiple, small	Rough in few, localized sites		
2.5	Moderate	Wrinkles at rest, multiple, localized, superficial	Localized, prominent NL/ML folds, jowels and SM	Yellow hue, PO and malar EB	Multiple, small and few large lentigines	Red E or multiple T, localized to 3 sites	Multiple, large	Rough in several localized areas		
3	Advanced	Wrinkles at rest, multiple, forehead, PO and perioral sites, superficial	Prominent NL/ML folds, jowels and SM, early neck strands	Yellow hue, EB involving PO, malar, and other sites	Many (10-20) small and large lentigines	Violaceous E or many T, multiple sites	Many	Rough in multiple, localized sites		
3.5	Advanced	Wrinkles at rest, multiple, generalized, superficial; few, deep	Deep NL/ML folds, prominent jowels and SM, prominent neck strands	Deep yellow hue, extensive EB with little uninvolved skin	Numerous (>20) or multiple large with little uninvolved skin	Violaceous E, numerous T, little uninvolved skin	Little uninvolved skin	Mostly rough, little uninvolved skin		
4	Severe	Wrinkles throughout, numerous, extensively distributed, deep	Marked NL/ML folds, jowels and SM, neck redundancy and strands	Deep yellow hue, EB throughout, comedones	Numerous, extensive, no uninvolved skin	Deep, violaceous E, numerous T throughout	No uninvolved skin	Rough throughout		

E, Erythema; EB, elastotic beads; ML, melolabial; NL, nasolabial; PO, periorbital; SM, submandibular; T, telangiectasia.

each category as well as overall.^{45,96} This grading scale may be employed in assessing the efficacy of any or all laser resurfacing technologies and cosmetic treatment modalities for their clinical impact on each individual aspect of the aging skin, providing a more quantitative analysis of each category as well as overall improvements.^{45,96} The grading scale has been tested in several studies of a nonablative combination device incorporating the three main classes of nonablative rejuvenation.^{45,47,96} The quantitative effects of the various technologies on each individual aspect of aging of the skin, rhytides, laxity, and the multiple parameters of photoaging, overall improvement, and patient satisfaction may now be calculated using such a grading system.

CONCLUSIONS

The field of laser skin resurfacing has evolved rapidly over the past 2 decades from ablative lasers, including CO₂ and Er:YAG, to nonablative systems employing near-IR, IPL, and RF systems, and most recently fractional laser resurfacing. The evolution of the nonablative and fractionally ablative resurfacing modalities has been spurred on by the demand for smaller but acceptable improvements in various or all aspects of skin aging, in the face of minimal-to-no down time and an excellent safety profile. A trend toward comprehensive, quantitative analyses and split-face, blinded evaluations are increasingly being employed to increase the reliability and accuracy of the clinical studies used to evaluate these modalities.

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