Cutaneous Resurfacing with CO\textsubscript{2} and Erbium: YAG Lasers: Preoperative, Intraoperative, and Postoperative Considerations

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The development and integration of pulsed and scanned CO\textsubscript{2} and erbium:YAG laser systems into mainstream surgical practice over the past years has revolutionized cutaneous resurfacing. These lasers are capable of delivering to skin high peak fluences to effect controlled tissue vaporization, while leaving an acceptably narrow zone of residual thermal damage. The inherent technological differences that exist between the two distant laser systems in terms of ablation depths, degree of thermal coagulation, and postoperative side-effects and complications guide patient selection and management.

This article reviews the basic principles of CO\textsubscript{2} and erbium:YAG laser resurfacing, including preoperative, intraoperative, and postoperative patient considerations. Side-effects and complications encountered after laser resurfacing are discussed with specific guidelines provided on their appropriate management. Anticipated future developments and cutting-edge research endeavors in cutaneous laser resurfacing are also briefly outlined.  (Plast. Reconstr. Surg. 103: 619, 1999.)

The elucidation of the principles of selective photothermolysis by Anderson and Parrish in 1983\textsuperscript{1} revolutionized the role of lasers in medicine, leading to their transformation into extraordinarily precise ablation tools and, thereby, paving the way for the development of today's resurfacing lasers. These two researchers demonstrated that it was necessary not only to employ a laser wavelength that would be selectively absorbed by the appropriate chromophore, but also to ensure that the pulse duration would be shorter than the thermal relaxation time of the tissue target (the time it takes for the target to cool to half of its peak temperature immediately after laser irradiation) while still delivering sufficient energy to produce the desired degree of damage. Today, both carbon dioxide (CO\textsubscript{2}) and erbium:YAG laser systems can achieve excellent cosmetic results by effacing photoinduced rhytides and dyschromia, ameliorating scars, vaporizing a wide range of other epidermal and dermal lesions, and improving the overall quality and texture of the skin.\textsuperscript{2-17}

The continuous-wave carbon dioxide laser, producing infrared light with a wavelength of 10,600 nm, was the first to be used for resurfacing procedures. Its wavelength is strongly absorbed by water, which is the most abundant chromophore in the skin and comprises approximately 70 percent of its total volume. This seemed to make it an ideal tool for generalized superficial ablation. But its tissue-dwell time could not be precisely controlled and far exceeded the 1-msec thermal relaxation time of the 20 to 30 \(\mu\text{m}\) of cutaneous tissue that absorbs CO\textsubscript{2} light. Excessive thermal diffusion and concomitant unintended tissue damage were the too-frequent results. Undesirable effects, such as char formation, pigmentedary changes, fibrosis, and scarring, could not be safely and reliably avoided, and the use of this laser for resurfacing was quickly abandoned.

However, in the early 1990s, new pulsed and scanning CO\textsubscript{2} lasers were developed that could deliver very high peak fluences of at least 5 \(\text{J/cm}^2\)—high enough to vaporize cutaneous tissue—in less than 1 msec.\textsuperscript{18} These instruments can precisely and safely remove thin layers of skin, between 20 and 30 \(\mu\text{m}\) with each pass, while leaving an acceptably narrow zone of residual thermal damage: 25 to 70 \(\mu\text{m}\), in con-
trast to the 200- to 600-μm zone produced by the continuous-wave CO₂ laser.¹⁹–²⁸

With the introduction of the pulsed erbium: YAG laser into the United States in mid-1996, an even more precise ablation tool became available. This laser emits infrared light with a wavelength of 2940 nm, far closer to the peak of the absorption spectrum of water than the 10,600-nm wavelength of the CO₂ laser (The absorption coefficient of water for erbium laser light is 12,800 cm⁻¹; for CO₂ light, it is 800 cm⁻¹). As a result, erbium laser light is absorbed 12 to 18 times more efficiently by cutaneous tissue than is CO₂ light.²⁷ Its penetration depth is between 2 and 5 μm instead of 20 to 30 μm, and it leaves a far narrower zone of residual thermal damage, on the order of about 20 to 50 μm.²⁷–³⁰ Thus, the erbium laser is capable of far finer superficial ablation than is the CO₂ laser.

In addition to differences in their ablation depths, the two lasers produce different kinds of tissue effects. The CO₂ laser’s effect is primarily photothermal, whereas the erbium laser’s effect is primarily photomechanical. The thermal effects of the CO₂ laser leave a relatively wide zone of coagulative necrosis, which results in highly effective hemostasis, and produce immediately visible collagen shrinkage of up to 25 percent during irradiation.³¹,³² In contrast, as a result of less extensive thermal diffusion, the erbium laser causes less coagulative necrosis, which permits more bleeding to occur intraoperatively, and collagen shrinkage is much less, amounting to only about 1 to 2 percent during irradiation (Table I).³³

The differences in ablation depths and the types of wounds produced by the CO₂ and erbium lasers guide patient selection, significantly affect the course of postoperative healing, and lead to divergent side effect and complication profiles. The indications for the use of each laser also differ, although the contra-

indications for each are substantially similar (Table II).³⁴ This article will review the issues of patient selection, intraoperative considerations, clinical effects, pretreatment and post-treatment guidelines, and the side effect and complication rates associated with each resurfacing laser system. It will conclude with a brief discussion of some of the likely future developments in cutaneous laser resurfacing. Areas of controversy exist in regard to almost every one of these topics. Because much remains to be learned regarding the science of laser resurfacing, the standards governing clinical practice are less than fully well defined. As a result, strategies for treating patients have continued to evolve since the procedure became widespread in the mid-1990s.

**Patient Selection**

The ideal patient for resurfacing with either the CO₂ or the erbium laser system has a fair complexion (skin prototype I or II) with lesions amenable to laser treatment and realistic expectations regarding what the surgery can accomplish and what the recovery period will entail. Individuals with darker complexions (types III through VI) can certainly be treated, but they are more likely to suffer undesirable pigmentary changes, and greater caution must be exercised when treating them. The major criterion governing the decision of which laser to use is the severity of the lesions under consideration.³⁵ Patients with mild-to-moderate photodamage or light scarring (Glogau classes I and II) can achieve excellent cosmetic results with the erbium laser (Figs. 1 and 2). However, those with moderate-to-severe photodamage or deeper scarring (Glogau classes III and IV) will achieve the best results with the CO₂ laser (Figs. 3 through 5). Additionally, those with more severe photodamage are often older than less-photodamaged individuals and, hence, in

<table>
<thead>
<tr>
<th>Laser Type</th>
<th>Advantages</th>
<th>Disadvantages</th>
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<tr>
<td>CO₂</td>
<td>More tissue contraction</td>
<td>Prolonged postoperative course</td>
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<td></td>
<td>Excellent hemostasis</td>
<td>Greater potential for development of hypopigmentation and scarring (due to thermal effect)</td>
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<td>Prolonged results with continued collagen remodeling</td>
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<tr>
<td>Erbium:YAG</td>
<td>Shorter postoperative recovery</td>
<td>Little to no tissue contraction</td>
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<td></td>
<td>Potentially fewer complications</td>
<td>Intraoperative bleeding</td>
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<td>More laser passes typically required (increase operative time)</td>
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<td></td>
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<td>Limited collagen remodeling (important for scar revision)</td>
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**Table I**

Advantages and Disadvantages: CO₂ versus Erbium Lasers
TABLE II
Cutaneous Laser Resurfacing: Indications and Contraindications

<table>
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<th>Indications</th>
<th>Relative</th>
<th>Contraindications</th>
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<tr>
<td>erbium/YAG</td>
<td>CO₂</td>
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<tr>
<td>Mild photodamage</td>
<td>Moderate to severe photodamage</td>
<td>Perpetual UVL exposure</td>
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<tr>
<td>Mild atrophic scars</td>
<td>Moderate atrophic scars</td>
<td>Collagen vascular or immune disorder</td>
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<tr>
<td>Mild dyspigmentation</td>
<td>Diffuse lentigines</td>
<td>Prior lower blepharoplasty (for infraorbital treatment)</td>
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<td>Refractory melasma</td>
<td>Mild dermatochalasis</td>
<td>Keloid tendency</td>
</tr>
<tr>
<td>Various epidermal/dermal lesions</td>
<td>Various epidermal/dermal lesions</td>
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UVL, ultraviolet light; HSV, herpes simplex virus.

Fig. 1. A 65-year-old woman with skin prototype I to II and minimal to moderate photodamage before (above, left) and 3 days after full-face erbium:YAG laser resurfacing (above, right). Two weeks after the procedure, minimal erythema remained (below, left). Clinical improvement remained apparent 1 year postoperatively (below, right).

greater need of the more extensive collagen-tightening effects achieved by the CO₂ laser.

The patient’s ability, on both a practical and an emotional level, to tolerate the extended period of convalescence after laser resurfacing must also be taken into account. In general, the recovery time required after erbium laser resurfacing is significantly shorter than it is with the CO₂ laser. The amount of time necessary for full reepithelialization can be up to twice as long for the CO₂ patient, and extreme erythema can last much longer as well—several months rather than several weeks. Individuals whose practical obligations prevent them from being able to take the time necessary for healing after CO₂ resurfacing, those who are temperamentally unsuited to remaining housebound for an extended period, and those who might have especially great difficulty tolerating the immediate negative effects of laser resurfacing on their physical appearance might be better suited for erbium resurfacing, even
when they have lesions that would be more effectively treated with the CO$_2$ laser. Of course, if such patients choose to undergo erbium resurfacing, it must be made clear that they will not be likely to achieve the same degree of lesion effacement that the CO$_2$ laser would provide.

Both the CO$_2$ and the erbium lasers can achieve excellent results with rhytides and dyspigmentation caused by photodamage in the perioral and periocular areas and the cheeks. Neither, however, is as effective in effacing movement-associated rhytides in the glabellar region and the nasolabial folds. Thus, whereas wrinkles caused by excessive ultraviolet light exposure are primarily indicated for resurfacing with either laser, those associated with movement are secondarily indicated. Atrophic scarring resulting from acne, varicella, or mechanical trauma is also a primary indication for resurfacing with either laser. The atrophic scars most responsive to resurfacing are those that are relatively shallow, soft, and distensible.

Extremely deep scars or pits bound with highly fibrotic tissue are far less responsive to either type of resurfacing. In these cases, an approach combining punch excision or grafting with laser treatment is more likely to achieve substantial improvement than the latter alone.

In addition to lesions associated with photodamage and atrophic scarring, both resurfacing lasers can treat other classes of lesions effectively. Again, the key to choosing the appropriate laser is the depth of involvement. Although the erbium laser can effectively treat deep dermal and superficial epidermal lesions, the ablation of deeper abnormalities can, generally speaking, be accomplished more efficiently with the CO$_2$ laser. Moreover, if a shave biopsy is required to diagnose a suspicious lesion suggestive of malignancy, the CO$_2$ laser’s greater hemostatic capability will prove especially useful. Epidermal and dermal lesions responsive to laser resurfacing include seborrheic keratosis, melasma, molluscum contagiosum, syringoma, epidermal nevus, dif-

Fig. 2. A 54-year-old woman with skin type II and minimal to moderate photodamage before full-face erbium: YAG laser resurfacing (above, left). After 4 days, minimal erythema and no crusting was seen (above, right). Improvement in skin tone and fine rhytides was observed 2 weeks (below, left) and 6 months postoperatively (below, right).
fuse lentigines, verruca vulgaris, actinic cheilitis, actinic keratosis, xanthelasma, sebaceous hyperplasia, trichoepitheliomas, and rhinophyma. The collagen-tightening effects of the CO$_2$ laser can also ameliorate mild dermatocchalasis.

Contraindications for erbium and CO$_2$ treatment are virtually identical. Absolute contraindications to laser resurfacing include isotretinoin use within 12 to 24 months of surgery, active bacterial or viral infections, the presence of ectropion (for infraorbital resurfacing), unrealistic patient expectations, and patient unwillingness or inability to comply fully with posttreatment care guidelines. Relative contraindications include extreme and habitual ultraviolet light exposure, collagen vascular disease, immune disorders, prior lower blepharoplasty (for infraorbital resurfacing), koebnerizing diseases, prior radiation therapy leading to a loss of adnexal structures, extensive fibrosis resulting from prior cosmetic treatments (e.g., dermabrasion, deep chemical peels, silicone injections), and a tendency to form hypertrophic scars or keloids.

**Intraoperative Considerations**

The goal of both CO$_2$ and erbium laser resurfacing is the clean, char-free, layer-by-layer ablation of skin, resulting in the absolute or relative effacement of lesions, while avoiding the creation of dermal injury so deep that hypertrophic scarring or other untoward complications result. Penetration into the papillary or upper reticular dermis represents the endpoint of safe treatment. Several factors determine the actual treatment parameters for each laser system, including the anatomic location being resurfaced, the patient’s skin type, individual tissue response to irradiation, and prior treatments to the area. In general, highly fibrotic areas, skin with more severe lesional involvement, and facial regions with thicker skin—the cheeks, chin, perioral area, and fore-
Fig. 4. A 58-year-old woman with skin phototype I and moderate photodamage with prominent facial rhytides before (above, left), 10 days after (above, right), and 6 months after full-face CO₂ laser vaporization (below).

head—require higher fluences and a greater number of laser passes. However, thin or delicate skin, such as that in the periocular area, or skin with fewer adnexal structures as a result of prior treatment requires lower energies and/or fewer passes. Moreover, patients with darker skin phototypes (III and above) run an ever-greater risk of adverse pigmen
tary changes as the depth of ablation increases. Thus, the aggressiveness of treatment should always be case-specific.

The surgeon should use energy densities equal to or exceeding the critical irradiance threshold (5 J/cm²) for tissue ablation when using either system. Lower irradiances are not as safe. Rather than cleanly vaporizing tissue, they heat it too slowly, thereby permitting greater heat conduction into surrounding tissues. Excessively deep thermal injury, or even charring, can result. Tissue vaporization should always be maximized and heat build-up in adjacent areas, minimized.

On average, CO₂ systems vaporize 20 to 60 μm of tissue with the initial pass. Residual thermal damage extends to a depth of 20 to 100 μm after a few passes. As a result of progressive tissue dissipation, each pass subsequent to the first vaporizes progressively less tissue while increasing the thermal build-up. The retained heat promotes the contraction of collagen, which is clearly visible during the second or third passes. Although this is a desirable effect, heat retention must be carefully controlled to prevent excessive coagulative necrosis, which can cause long-lasting erythema, increased postoperative pain, a too-distinct delineation between treated and untreated areas, and more serious sequelae, including fibrosis and scar formation.

The first pass with a CO₂ laser will vaporize all or most of the epidermis. Because CO₂ ablation is primarily thermal, each pass will leave behind a detritus of coagulated necrotic tissue. This whitish debris must be thoroughly re
moved with saline-soaked gauze; if allowed to remain, it can act as a heat sink and promote excessive thermal damage with successive laser passes. Moreover, the removal of necrotic tis-
Erbium resurfacing systems typically vaporize 2 to 5 μm of tissue per pass and leave a 20- to 50-μm zone of residual thermal damage. In contrast to CO₂ resurfacing procedures, surgeons currently use energy densities far exceeding the critical irradiance threshold for erbium systems. On average, these range from 5 J/cm² for the delicate periorbital area and superficial lesions and up to 12 to 15 J/cm² for thicker, heavily photodamaged skin and deeper lesions. Ablation depth is directly proportional to energy density; thus, erbium laser systems can be more finely tuned than can CO₂ systems, lending them greater versatility. Moreover, in contrast to CO₂ laser ablation, the depth of ablation caused by erbium laser irradiation does not progressively diminish after multiple passes because the zone of residual thermal damage is comparatively minimal. Thus, erbium laser systems are particularly useful when extremely precise, finely adjusted light-to-medium ablation is appropriate.

However, erbium systems are neither as effi-
cient nor as controllable as CO₂ systems when deep ablation is necessary. Surgeons must perform approximately three to four times as many passes with an erbium laser as they would with a CO₂ system to achieve the same depth of vaporization. Typically, full ablation of the epidermis requires two or three passes at 5.0 J/cm². Extremely photodamaged areas or deep dermal lesions may require as many as nine passes with an erbium laser; in contrast, a CO₂ laser would probably treat such areas in two to four passes. Moreover, the wound depth created by the erbium laser becomes less uniform after a large number of passes and, in consequence, healing becomes less predictable. Using the appearance of the surgical field between multiple passes as a guide for uniform ablation is more difficult with erbium systems than it is with CO₂ systems, because the injury produced is primarily photomechanical. On impact, the erbium laser beam forcibly ejects desiccated tissue at supersonic speeds—hence, the distinctive skin popping during ablation—and the superficially whitened area left behind quickly fades into inconspicuousness, offering the surgeon less guidance when treating large adjacent areas of the dermis than does the coagulated tissue remaining after CO₂ irradiation. Because little necrotic tissue remains after erbium laser impact, wiping the skin between passes is not typically necessary, as it is after CO₂ irradiation. Deep ablation with the erbium laser is rendered even more difficult by its inferior hemostatic abilities; once the surgeon penetrates into the papillary dermis, pinpoint bleeding becomes more and more frequent, obscuring the surgical field. Such bleeding indicates the endpoint of treatment, even when lesions have not been completely erased. Thus, CO₂ systems offer the surgeon a more “foolproof” and efficient tool for deep ablation.

Currently, some laser surgeons are beginning to combine CO₂ and erbium resurfacing treatments to take greater advantage of the unique properties offered by each system. In contrast to the early days of high-energy pulsed and scanned CO₂ laser resurfacing, a far greater proportion of full-face procedures is now performed. Full-face resurfacing offers many advantages over partial procedures: obvious lines of demarcation and subsequent textural differences between treated and untreated areas of the face can be avoided; the collagen-tightening effects of the CO₂ laser are more pronounced after a full-face procedure; and patients can more easily conceal lingering erythema or transient pigmented changes when the face is uniformly treated. Obviously, many patients who present for laser resurfacing have highly uneven areas of photodamage, scarring, or other types of lesional involvement. Using an erbium laser on less damaged areas while reserving the CO₂ laser for more heavily damaged or diseased areas may provide surgeons with the means to match resurfacing procedures more exactly to the needs of individual patients. More controversial, however, is the use of the erbium laser to remove a portion of the zone of residual thermal damage remaining after CO₂ resurfacing. The role that such thermal damage plays in wound healing and collagen shrinkage after resurfacing remains poorly understood. More research is needed to determine whether the removal of part of this zone of thermally damaged tissue will ultimately have a positive or deleterious effect—or perhaps no effect at all—on the healing processes and ultimate clinical outcome of CO₂ laser resurfacing.

**Clinical Effects**

Resurfacing the skin with either the CO₂ or the erbium laser system results in the oblitera-
tion of the epidermis and the partial ablation or coagulative necrosis of the upper dermis, along with concomitant wounding of deeper regions. Atypical, disorganized epidermal cells are replaced with normal, well-organized cells migrating from the follicular adnexae during initial reepithelialization. The zone of solar elastosis in the superficial papillary dermis—consisting of irregular, highly disorganized masses of amorphous elastotic material—coagulated or vaporized during laser irradiation is replaced with normal, compact collagen and elastin organized in regular, parallel alignment during the remodeling phase. Reversible damage to the deeper regions of the dermis results in immediate collagen shrinkage—up to 25 percent with the CO₂ laser and 1 to 2 percent with the erbium laser—and subsequent wound contraction.

Histologic studies of the effects of laser irra-
diation on human skin are relatively recent. Although the effects of tissue ablation are comparatively clear, much remains to be investigated regarding the mechanisms and effects of collagen contraction after CO₂ laser irradiation. Contraction observed intraoperatively
may be related either to thermal desiccation or to true collagen shrinkage, because heat-induced contraction occurs at temperatures of 55 to 62°C. This thermally induced effect persists for a very short period—about 14 days—and explanations for the persistent collagen-tightening effects of CO₂ laser resurfacing are being sought. It has been postulated that the initial shrinkage, although temporary, may provide a matrix for newly formed collagen that recapitulates the shortened form. In addition, new fibroblasts migrating into laser-induced wounds express an increased number of immunofactors that could help to account for persistent collagen shrinkage. The most important of these is smooth muscle actin, which indicates an increase in contractile actin filaments. These contractile filaments may create a smaller wound surface area, providing a contracted scaffolding for the further deposition and organization of collagen. Other cytokines, such as integrins, may also contribute to persistent collagen contraction. Clearly, more investigation into the process of laser-induced wound healing is necessary before the complete explanation is clear.

Reported rates of lesion improvement after both CO₂ and erbium laser irradiation have been impressive. Most studies indicate an average clinical improvement of rhytides and atrophic scars greater than 50 percent. Patients who have photodamaged skin with limited tissue fibrosis and predominantly non-movement-associated rhytides tend to show the most improvement when compared with those with atrophic scars and increased fibrosis from previous treatments.

**Pretreatment and Posttreatment Guidelines**

Wide divergences exist regarding certain aspects of the pretreatment regimen and postsurgical care best suited for laser resurfacing patients, regardless of whether the laser system used is CO₂ or erbium. A lack of consensus exists regarding, in particular, whether the patient’s skin should be pretreated for several weeks before surgery with topical tretinoin, alpha-hydroxy acids, and/or bleaching agents, such as hydroquinone, to enhance healing or to reduce the incidence of transient hyperpigmentation after surgery. Disagreement also exists regarding the question of which technique—open or closed wound dressings—most effectively reduces postoperative morbidity and encourages rapid healing. Recently, the use of prophylactic antibiotics has come under debate. To answer these questions definitively, more controlled studies need to be performed.

According to a recent (1998) survey of physician members of the American Society of Laser Medicine and Surgery, 80 percent of the 116 respondents reported that they pretreat cutaneous laser resurfacing patients with topical tretinoin, whereas 34 percent prescribe glycolic acid cream and 69 percent use hydroquinone. These numbers substantially agree with the figures reported in a 1997 survey conducted jointly by the American Society for Aesthetic Plastic Surgery and the American Society of Plastic and Reconstructive Surgeons. The latter survey revealed that only a minority (13 percent) of physicians reported the lack of a prescribed skin care regimen during the weeks before surgery. Several reports have indicated an acceleration of postoperative reepithelialization with the use of topical tretinoin before dermabrasion or deep chemical peels. Although it is possible, perhaps even likely, that presurgical topical tretinoin use could have a similar effect on laser resurfacing patients, the question of whether these findings can be applied to this patient population remains problematic because laser-induced cutaneous wounds differ substantially from those resulting from other resurfacing procedures.

Discovering effective means for preventing transient hyperpigmentation after cutaneous laser resurfacing is clearly of great importance in patient care because it is by far the most common complication observed postoperatively. As many as one-third of all laser resurfacing patients experience some degree of hyperpigmentation after surgery; moreover, the darker the patient’s skin phototype, the higher the incidence. Because hydroquinone is cytotoxic to melanocytes and inhibits tyrosinase, thereby decreasing melanosome formation, many authors have assumed that pretreatment with the drug may decrease the incidence of postoperative hyperpigmentation. However, a controlled study of 100 patients in whom preoperative topical tretinoin, hydroquinone, and/or glycolic acid was used indicates that the presurgical use of hydroquinone has no significant effect on posttreatment hyperpigmentation, presumably due to the fact that the epidermis is repopulated by melanocytes originating from deep within the follicular unit. On the other hand, the postoperative
use of topical tretinoin, glycolic acid, and hydroquinone, and periodic light glycolic acid peels, can help reduce the duration and severity of post-laser hyperpigmentation once it is clinically detectable.

Although the efficacy of these pretreatment skin-care regimens is not yet unambiguously established, one aspect of presurgical care is clearly essential: the education of the laser resurfacing patient. Such education not only helps to establish a sense of rapport between physician and patient, which in itself can positively affect the postoperative course, but also may help to prevent adverse postoperative psychological sequelae and ensure patient compliance with posttreatment care guidelines. Many potential patients present with unrealistic expectations regarding what cutaneous laser resurfacing can accomplish and what the postoperative period will entail. Further, several psychological surveys have shown that when potential patients present for cosmetic procedures, they have already made the emotional commitment to undergo surgery and attend only selectively to the information presented by the physician, retaining only that which reinforces their initial decision. Every effort should be made to render patients fully cognizant not only of the benefits of cutaneous laser resurfacing, but also of its limits. Possible posttreatment side effects and complications should be thoroughly discussed. Ideally, such information should be presented repetitively and in a variety of formats: through conversations with the surgeon and members of the staff; through photographs and videos; and in written form. Physicians should also stress that the recovery period after cutaneous laser resurfacing is prolonged and that the final results depend not only on the surgical procedure itself, but also on the quality of postoperative care that takes place, for which the patient is, of course, partially responsible.

During the period immediately after cutaneous laser resurfacing and before full reepithelialization has occurred, the laser-induced wound must be kept moist, whether an open or closed technique of wound dressing is chosen. Partial-thickness cutaneous wounds heal more quickly and with a much reduced risk of scarring if they are maintained in a moist environment, because the presence of a dry crust or scab impedes keratinocyte migration. Although there is consensus on this principle, disagreement exists on the best way to accomplish the goal. When cutaneous laser resurfacing first became widespread, most surgeons favored an open technique of wound dressing. With the increasing number of full-face procedures that were subsequently performed, a larger number of surgeons began favoring a closed technique. Many argued that semicclusive biosynthetic dressings, such as Flexzan, Second Skin, and Vigilon, both increased the rate of reepithelialization and substantially decreased the patient’s postoperative pain. Some also observed that the use of such dressings rendered postoperative care less dependent on patient compliance. The 1997 joint survey by the American Society for Aesthetic Plastic Surgery and the American Society of Plastic and Reconstructive Surgeons reported that respondents were almost evenly divided in their choice of a closed or an open technique. However, it has become apparent that the extended use of semicclusive dressings is not without its drawbacks; extended use can lead to wound maceration and a greater incidence of infection. Further, such dressings may interfere with visual inspection of the wound, making it difficult to detect the early onset of infection. Therefore, many surgeons are favoring the use of an open wound-care technique, with such healing ointments as Catrix 10, Aquaphor, Theraplex, Elta, or plain petrolatum. Others recommend the use of biosynthetic dressings for strictly limited periods of time, either for the first several hours after surgery, or nightly until reepithelialization has occurred.

Some aspects of drug treatment after cutaneous laser surgery are agreed upon, whereas others, particularly the prescription of prophylactic antibiotics, are more controversial. Undoubtedly, antiviral prophylaxis is essential. Approximately 2 to 7 percent of all laser resurfacing patients experience infection with the herpes simplex virus. Latent herpes reactivation after laser resurfacing, especially in the perioral area, is the primary source of infection. Even patients with no previous history of overt herpes outbreaks can experience an active infection before reepithelialization is complete. Accordingly, 96 percent of the respondents to the 1998 survey cited above prescribe antiviral drugs (Zovirax, Valtrex, Famvir). The prescription of prophylactic antibiotics, however, is more controversial because of the danger of encouraging the development of drug-resistant strains of bacteria. The recent
appearance of a deadly vancomycin-intermediate-resistant strain of *Staphylococcus aureus* in the United States offers ample proof of the dangers involved. Although the majority of surgeons presently do prescribe routine antibiotics as prophylaxis against Gram-positive organisms, some researchers have recently begun to question whether such drugs should be used before an infection is suspected; the practice advocated by burn surgeons is not to treat until the patient is symptomatic. Lastly, the use of postoperative corticosteroids to reduce the signs of inflammation (in particular, edema) may also account for delayed wound healing and should be evaluated.

**SIDE EFFECTS AND COMPLICATIONS**

The side effect and complication rates after CO₂ laser resurfacing are relatively low, and those for erbium resurfacing may prove to be even lower yet once extensive data have been compiled, because the latter is a less invasive procedure and reepithelialization occurs more rapidly. According to a recent survey of 100 patients—half treated with erbium, half with CO₂—an average of 5.5 days was required for reepithelialization in erbium-treated patients, whereas 8.5 days was needed for those treated with the CO₂ laser. However, serious side effects, such as scarring, adverse pigmentation and textural changes, and infection, can occur after any cutaneous resurfacing procedure, even in the hands of the most experienced laser surgeon. During the immediate postoperative period, therefore, vigilance is necessary, along with prompt and aggressive intervention should complications arise.

All laser resurfacing patients, regardless of the system with which they are treated, experience postoperative edema and erythema, as these sequelae are part of the normal inflammatory response. The duration of erythema is significantly less for patients treated with the erbium laser than it is for those treated with the CO₂ laser—on average, 2 to 4 weeks as opposed to 3 to 6 months for CO₂ patients. The intensity and duration of erythema correlates directly with the depth of ablation and degree of residual thermal damage, hence, its lessened severity for erbium-treated patients. Postresurfacing erythema has been shown to be diminished with the postoperative use of topical ascorbic acid due to its presumed anti-inflammatory effect. During the immediate postoperative period, before reepithelialization is complete, both groups of patients also universally experience serous discharge, crusting, and burning discomfort. Patients treated with the erbium system also frequently experience spot bleeding during the first 24 to 48 hours after surgery.

Mild complications after cutaneous resurfacing with either laser system include milia formation, acne exacerbation, and irritant or allergic contact dermatitis. More serious complications include localized bacterial or fungal infections, regional herpes simplex reactivation, and pigmentary alteration (hyperpigmentation). The most severe complications and, fortunately, the rarest, are hypertrophic scarring, ectropion formation, and disseminated infection (Table III).

The necessity for highly occlusive dressings and thick emollient ointments, and aberrant follicular reepithelialization, makes milia formation and acne exacerbation fairly common occurrences after laser resurfacing. After reepithelialization is complete, topical retinoic, glycolic, and/or azelaic acid may reduce the incidence and severity of milia and acneiform lesions.

Contact dermatitis or eczematization, most often caused by an irritant rather than an allergic reaction, is also quite common among cutaneous resurfacing patients due to the decreased barrier function of the reepithelialized tissue. As many as 65 percent of patients experience a reaction to topical preparations before, or even after, full reepithelialization has taken place. The most com-

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<td>Transient hyperpigmentation</td>
<td>Hypertrophic scarring</td>
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<td>Crusting/edema</td>
<td>Delayed hypopigmentation</td>
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<td>Allergic/irritant dermatitis</td>
<td>Localized bacterial/fungal infection</td>
<td>Disseminated infection</td>
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<tr>
<td>Milia</td>
<td>Regional herpes simplex viral reactivation</td>
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mon irritants include antibiotic ointments (neomycin, polysporin, or bacitracin), corticosteroid cream bases, fragrance-containing compounds, and chemical sunscreens. Some patients succumb to the temptation to medicate themselves, often with so-called "natural" remedies, during the postoperative period; hence, aloe vera is another compound that frequently causes irritant reactions. The incidence of contact dermatitis may prove to be lower after erbium:YAG laser resurfacing because reepithelialization occurs more quickly—usually within approximately 4 to 5 days, compared with the 7 to 10 days after CO₂ laser vaporization.

Among moderately serious complications, postraustratic pigmentary disturbances are the most common. Hyperpigmentation occurs in more than one-third of all patients; for patients with the darkest skin phototypes, the incidence approaches 100 percent. The condition usually becomes apparent about 4 weeks after surgery. Fortunately, it is transient, although inconvenient and sometimes emotionally disturbing for the patient. It will usually resolve spontaneously, but its resolution can be hastened with topical glycolic, azelaic, or retinoic acid, light glycolic acid peels, and/or topical hydroquinone, along with regular sunscreen use. It has only recently become apparent that hypopigmentation can also occur after laser resurfacing, but less frequently than hyperpigmentation and with a delayed onset (6 to 12 months postoperatively). It may be caused by damage to follicular melanocytes resulting from overly aggressive laser treatment or may simply be unmasking preexisting hypopigmentation resulting from earlier trauma (e.g., dermabrasion, phenol peel). Unfortunately, unlike hyperpigmentation, its appearance is, apparently, permanent and can only be reduced by treating surrounding areas of dyspigmentation (e.g., adjacent neck regions) with peeling agents. The risk of hypopigmentation may be lower in patients undergoing erbium:YAG laser resurfacing; however, postoperative hyperpigmentation rates seem to be the same between erbium:YAG and CO₂ laser resurfacing (personal observation).

Viral, bacterial, and fungal infections usually occur during the first postoperative week, before full reepithelialization has occurred. Herpes outbreaks occur in about 2 to 7 percent of all laser resurfacing patients, even with appropriate antiviral prophylaxis. The most common bacterial infections are those caused by Staphylococcus aureus. Due to the necessity of maintaining a moist wound environment, Pseudomonas and Candida infection can also take place; the latter especially is seen among women with chronic vaginal yeast infections. Severe cutaneous infections, of course, can severely disrupt and prolong the healing process. Prompt, aggressive treatment is necessary to prevent the development of scarring or the systemic spread of the infection.

The most severe complications—hypertrophic scarring, ectropion formation, and systemic infection—occur in less than 1 percent of all laser resurfacing patients. Hypertrophic scarring, the most common of these sequelae, usually becomes apparent within the first couple of months after laser resurfacing. The perioral, chin, mandible, and neck regions are the areas most prone to such scarring. The aggressiveness of treatment—the energy densities used, the number of passes performed, and the overlapping placement of scans or spots—can influence the risk of scarring. Irradiation with a 585-pulsed dye laser can improve the clinical and histologic appearance of hypertrophic scars and can also reduce associated symptoms, such as pruritis and dysesthesia. Hypertrophic scarring can also be treated with intralesional steroids and/or silicone gel sheeting; however, these strategies are generally less effective and less well tolerated. The exact rate of incidence of ectropion formation is not yet clear, but the condition appears most often among patients who have had lower blepharoplasties before laser resurfacing and/or received overly aggressive infraorbital resurfacing. Most often, surgical intervention is necessary to correct the condition.

**Future Directions**

In general, future developments in cutaneous laser surgery will allow for more precise tissue ablation with even less risk of excessive thermal damage due to further realization of the principles of selective photothermolysis. Among the most interesting of the innovative techniques in cosmetic laser surgery now appearing on the horizon is subepidermal ablation or intradermal heating using new laser technology and dynamic cooling. Research into this technique is now being conducted with a 1320-nm neodymium:YAG laser, which produces energy fluences of 10 to 25 J/cm² and has a pulse duration of 200 msec. This
laser can, thus, deliver energy at higher fluences in a shorter period of time than can either the pulsed CO₂ or erbium laser. A cryogen is sprayed on the epidermal surface to cool and protect it immediately before laser irradiation. In this way, all of the laser's energy is directed into the dermis, where ablation and coagulation take place. This technique may serve to reduce postoperative morbidity among patients who do not require epidermal ablation, while still allowing them to benefit from the dermal remodeling process. However, clinical application of this resurfacing technique may be somewhat limited in older patients, who often present with severe epidermal and dermal involvement due to excessive and cumulative photodamage. Nonetheless, subepidermal laser resurfacing will present yet another important treatment modality, permitting the surgeon even greater flexibility in answering the needs of individual patients. Other systems are now being investigated as cutaneous resurfacing tools, including the titanium:sapphire laser, the holmium:YAG laser, various diode and excimer lasers, and electro-surgical coblation. With each new development, both the surgeon and his or her potential patients will undoubtedly gain greater access to the most precise and appropriate possible treatment and, hence, the best possible results.

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