CURRENT CONCEPTS

Review of Cutaneous Lasers and Their Applications

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ABSTRACT

Background. The use of lasers has assumed an increasingly important role in the treatment of a variety of cutaneous lesions over the past few decades. Because of their effectiveness, physicians from a variety of specialties have incorporated lasers into their practices. Unfortunately, widespread availability of lasers and the public's fascination with their potential uses have created extraordinary, often unrealistic, expectations.

Methods. We review the laser systems most frequently used to treat skin conditions.

Results. We discuss lasers with specificity for vascular malformations and pigmentary disorders as well as for tattoos and scars. Also, we review the latest techniques for cutaneous laser resurfacing with carbon dioxide and erbium:YAG lasers. Last, we briefly outline future uses of lasers and ongoing investigations, including laser treatment of leg veins and laser-assisted hair removal.

Conclusions. Lasers, when properly used, offer clear advantages when compared with older, traditional approaches. Laser technology is clearly at its best when the characteristics of selectivity and specificity apply. Significant improvement and even elimination of many cutaneous lesions can now be accomplished with reduced risks to the patient when proper patient selection and laser treatment parameters are chosen.

AS LASER TECHNOLOGY continues to evolve, treatment options for a variety of cutaneous lesions expand and improve. The advent of new lasers with innovative technology will continue to set high standards in the treatment of vascular, pigmented, tattooed, and scarred lesions. We review the different lasers available for use in various cutaneous conditions.

LASER BASICS

The first laser was developed in 1959, 32 years after Einstein had proposed the concept of stimulated emission. In 1963, dermatologist Leon Goldman was the first physician to test this prototype ruby laser in human skin.[1]

Laser, an acronym for light amplification by stimulated emission of radiation, has several therapeutically physical properties: (1) monochromaticity—the ability to selectively target chromophores with an appropriately single wavelength; (2) coherence—the proper alignment of light waves, allowing high intensity to be focused over a small area; (3) compressibility—the use of ultra short pulses that delivers localized energy; and (3) collimation—the transmission of parallel rays of light without divergence or loss of intensity as the distance increases, thus creating a spot size that is maintained over a wide distance. Selective target destruction occurs if the laser wavelength is appropriate and the light exposure time (pulse duration) is shorter than the time it takes for heat to diffuse from the target (thermal relaxation time).[2,3] This theory of "selective photothermolysis" is important when treating small cutaneous targets to prevent unnecessary tissue damage that could lead to scarring or unwanted pigmentary changes.

LASER TYPES

Continuous wave (CW) lasers (argon, krypton, older Nd:YAG and CO_2 lasers) emit a constant beam of light in contrast to the pulsed lasers (510 and 585 nm pulsed dye, Q-switched or QS ruby, QS Nd:YAG, QS alexandrite) that produce interrupted bursts of high energy light. In general, selective photothermolysis of various cutaneous lesions is better achieved using pulsed laser technology

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TABLE 1. Different Lasers and Their Applications

Laser Type	*Wavelength*	*Applications*
Ruby (Q-switched)	694 nm	Pigment, dark tattoo
(Long-pulsed)		Hair
Alexandrite (Q-switched)	755 nm	Pigment, dark tattoo
(Long-pulsed)		Hair
Nd:YAG (Q-switched)	1,064 nm	Pigment, dark tattoo
(Long-pulsed)		Hair
Frequency-doubled Nd:YAG	532 nm	Superficial pigment, red tattoo
Pulsed dye	510 nm	Superficial pigment, red tattoo
	585 nm	Vascular, scars, warts, striae
Potassium titanyl phosphate (quasi-CW)	532 nm	Pigment, vascular
Copper vapor/bromide (quasi-CW)	510 nm	Pigment
	578 nm	Vascular
Tunable dye argon (quasi-CW)	577/585 nm	Vascular
Erbium:YAG (pulsed)	2,940 nm	Skin resurfacing*
CO_2 (continuous wave)	10,600 nm	Actinic cheilitis, verrucae
CO_2 (high-energy, pulsed)	10,600 nm	Skin resurfacing*

*Rhytides, atrophic scars, epidermal/dermal lesions.

because of the short thermal relaxation times of cutaneous chromophores such as hemoglobin and melanin. Each laser system has different clinical applications, depending on its wavelength and pulse duration (Table 1).

PIGMENT LASERS

Q-Switched Ruby Laser (694 nm)

The ruby laser was the first to be shown effective in the treatment of dermal pigmentation without scarring. Quality or "Q"-switching of the laser light permitted the production of energy densities (fluences) of up to 10 J/cm^2, thereby improving tissue heating and destruction. Because melanin absorbs light well in the deep red portion of the electromagnetic spectrum, the 694 nm wavelength of the ruby laser with a 20 to 40 nanosecond (ns) pulse duration is perfect for selective absorption by melanosomes. Another benefit of this laser is the greater dermal depth of penetration of its long wavelength, being particularly useful for the treatment of deep pigmented lesions such as nevus of Ota.

The laser-irradiated skin shows immediate and transient whitening, lasting up to 30 minutes, followed by erythema and swelling for 30 to 60 minutes. Vesiculation may occur in 24 to 36 hours, and healing is complete by 10 to 14 days.

The ruby laser is successfully used for the treatment of solar lentigines (5 to 6 J/cm^2, 1 to 2 treatments) and ephelides,[4] isolated labial lentigos or in association with Peutz-Jeghers syndrome,[1,5,6] nevus of Ota (5 to 6 J/cm^2, 4 to 6 treatments),[7-11] blue nevi, as well as other melanocytic nevi.[12,13] Ruby laser irradiation of Becker's nevus, nevus spilus, and café-au-lait lesions (5 to 6 J/cm^2, 3 to 4 treatments) are associated with a high rate of recurrence, usually seen within 6 to 12 months after treatment.[4,14] Postinflammatory hyperpigmentation and melasma are not typically responsive to the ruby laser.[15] Complications of treatment are temporary hypopigmentation (lasting 2 to 6 months), transient hyperpigmentation (in 15% of cases), and rarely permanent depigmentation. The incidence of scarring or epidermal atrophy is <5%.

Q-Switched Alexandrite Laser (755 nm)

The Q-switched alexandrite laser emits red light at a slightly longer wavelength (755 nm) and pulse duration (50 to 100 ns) than the ruby laser. Treatment is usually initiated at a fluence of 6.0 to 6.5 J/cm^2 with a 3 mm spot size. Repeat treatments are delivered at 6- to 8-week intervals to allow for adequate tissue healing. As with the ruby laser, the Q-switched alexandrite laser can also be used to treat epidermal and dermal pigmented lesions, such as solar lentigines (Fig 1), benign melanocytic nevi, and nevus of Ota.[16,17] Similar to other pigment-specific lasers, recurrence of café-au-lait macules has been reported after treatment. Transient hypopigmentation after treatment is not as commonly observed as after ruby irradiation.

Q-Switched Nd:YAG Laser (1,064 nm, 532 nm)

The Nd:YAG laser emits an infrared light at 1,064 nm with a pulse duration of 10 ns. Frequency doubling of the 1,064 nm wavelength will result in a 532 nm visible green light. The shorter 532 nm wavelength is better used for the treatment of lentigines, café-au-lait macules, and other epidermal pigmented

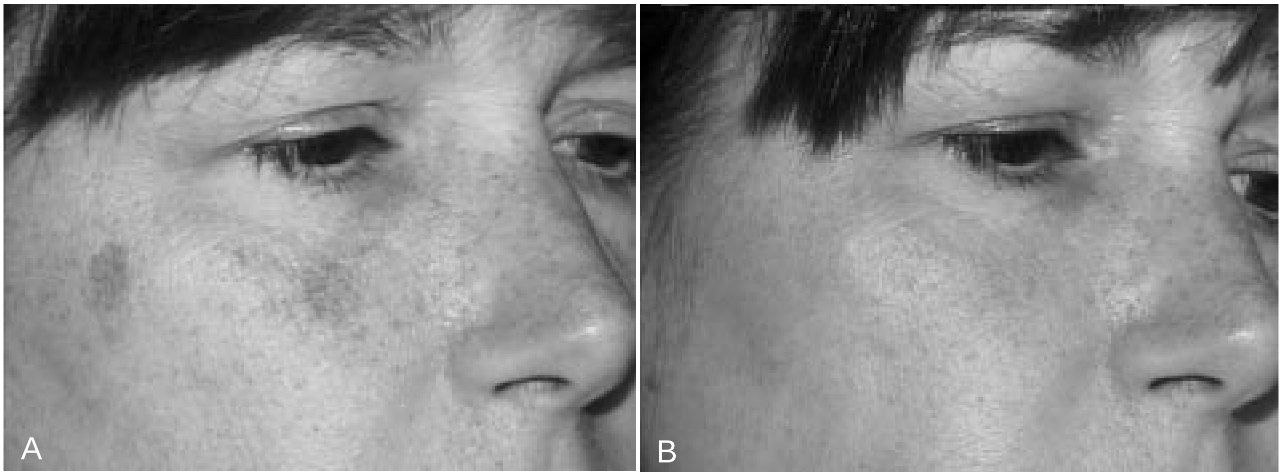

FIGURE 1. Solar lentigo on temple of 42-year-old woman (A) before and (B) 6 weeks after Q-switched alexandrite laser treatment. (Any pigment-specific laser system would be expected to yield similar clinical results.)

lesions,[18-20] whereas the longer 1,064 nm wavelength is used for treatment of deep dermal pigment, such as in nevus of Ota and other melanocytic nevi. Typically, 2 to 5 treatments are required at an average fluence of 8 J/cm^2 with a 3 mm spot size to effect the desired degree of lightening.[19] Complications include hypopigmentation or hyperpigmentation and transient textural changes at higher fluences.

Pigmented Lesion Dye Laser (510 nm)

The pigmented lesion dye laser emits a green light at 510 nm with a 300 ns pulse duration. It is proven effective in the treatment of epidermal pigmented lesions, including café-au-lait spots and solar lentigines.[21-26] Unlike solar lentigines, which clear after 1 to 2 treatments at 2.5 J/cm^2, café-au-lait macules usually require multiple laser sessions (6 to 8 treatments) at 2-month intervals, using fluences of 2.5 to 3.5 J/cm^2. Transient pigmentary changes are observed in 15% of treated café-au-lait lesions.

Copper Vapor Laser (578 nm)

The copper vapor laser emits a green light at 510 nm and a yellow beam at a wavelength of 578 nm. Brief 20 ns pulses are delivered with 67 μs intervals between pulses. The ability of this laser to emit pulses at a high repetition rate (15,000 pulses/sec = 15 kHz) qualifies this system as a quasi-CW laser. At 510 nm, lentigines, café-au-lait macules, and dermatosis papulosa nigra can be successfully treated, whereas at 578 nm, vascular lesions such as telangiectasias can be targeted.[27] Because of the quasi-CW nature of this laser system, nonspecific tissue thermal damage may occur with increased risk of pigmentary and textural skin changes.

TABLE 2. Laser Treatment of Different Color Tattoo Inks

Laser Type	*Black*	*Green*	*Red*	*Tan*
Ruby/694 nm	+++	++	–	Darkening
Alexandrite/755 nm	+++	+++	–	Darkening
Nd:YAG/1,064 nm	+++	+	–	Darkening
Frequency-doubled Nd:YAG/532 nm	–	–	+++	Darkening
Flashlamp-pumped pulsed dye/510 nm	–	–	+++	Darkening

TATTOO LASERS

Before laser technology, exogenous pigment was treated with more damaging techniques such as dermabrasion and excision, resulting in scar formation or pigmentary changes. Lasers have revolutionized the treatment of tattoos, offering acceptably desirable results.

The older laser systems, such as the CW CO_2 and argon lasers, also led to scarring due to excessive thermal injury of normal skin. The Q-switched lasers that produce ultra short pulses of high energies literally shatter tattoo ink particles without destruction of the surrounding tissue. The resultant injury is followed by phagocytosis, lymphatic transportation, and/or transepidermal extrusion of the fragmented ink particles.

Professional tattoos are more difficult to treat than the amateur variety, because they are comprised of multicolored organometallic dyes that are placed deeper and more densely packed in the skin. Amateur tattoos often require 4 to 6 laser treatments, whereas professional ones require 8 or more sessions.

All previously described pigment-specific Q-switched lasers can be used in the treatment of

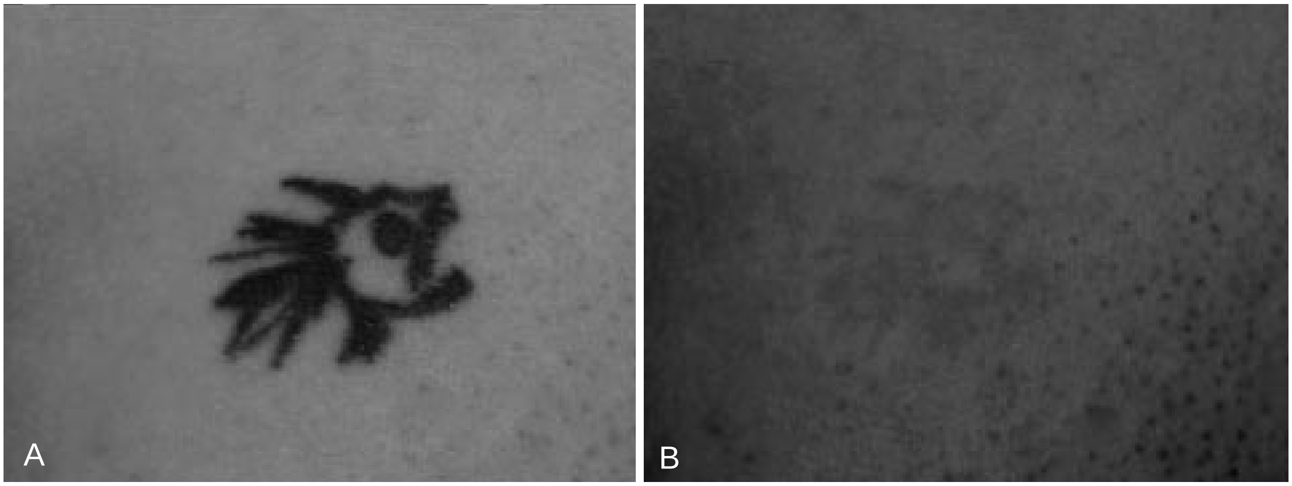

FIGURE 2. Blue-black tattoo (A) before and (B) 8 weeks after eighth Q-switched laser treatment. (QS ruby, alexandrite, and Nd:YAG lasers produce similar results.)

tattoos with varying efficacy, depending on the ink color (Table 2). The three Q-switched laser systems previously mentioned (ruby, alexandrite, Nd:YAG) can all remove blue-black tattoo ink with equal efficacy[28-40] (Fig 2). Fluences of 6 to 8 J/cm^2 are used, leading to immediate tissue whitening of the treated area. The ruby laser is least effective in treating red ink; however, the alexandrite and 1,064 nm Nd:YAG lasers are also relatively ineffective. Red tattoos can be easily removed within two to four sessions using green wavelength lasers (510 nm pulsed dye or 532 nm frequency-doubled Nd:YAG). Complications observed after Q-switched laser irradiation of tattoos include hypopigmentation (due to concomitant melanin destruction), systemic allergic reaction (due to release of extracellular ink particles with high antigenicity, eg, chromium-containing red or yellow inks),[41] and tattoo ink darkening (due to Q-switched induced oxidation-reduction reaction of iron oxide or titanium oxide-containing tattoos).[42]

VASCULAR LASERS

The peak absorption wavelength of oxyhemoglobin occurs in the yellow portion of the electromagnetic spectrum. In accordance with the principles of selective photothermolysis, a pulse duration shorter than 1 ms is needed for targeting small caliber blood vessels and effecting blood coagulation.

Flashlamp-pumped Pulsed Dye Laser (585 nm)

The initial reports on the vascular effect of the flashlamp-pumped pulsed dye laser used a 577 nm wavelength. However, subsequent research revealed that at a longer wavelength of 585 nm tissue penetration could be increased without losing vascular specificity. Furthermore, unwanted hypopigmentation was less frequently observed due to decreased absorption of 585 nm light by melanin. Nonetheless, it is always important to remember that since epidermal melanin interferes with absorption of the 585 nm pulsed dye laser pulses, energy delivery will be lower through more deeply pigmented skin. Spot sizes vary from 5 to 10 mm and fluences range from 4 to 9 J/cm^2. By increasing the spot size, deeper tissue penetration is obtained. If a smaller spot size is used, a higher fluence is needed to produce the same clinical results.

The vascular-specific pulsed dye laser was developed primarily for the treatment of port-wine stains (6.0 to 7.0 J/cm^2, spot size 5 to 7 mm),[43-47] but it is now considered to be the standard for the treatment of several different vascular lesions, including telangiectasias, spider angiomas, superficial hemangiomas, and pyogenic granulomas.[48-60] Purpuric macules develop immediately after treatment and typically resolve within 1 to 2 weeks. Scaling (12%) and crusting (4%) may occur after treatment. Blistering and scarring are complications reported in fewer than 1% of cases and are associated with delivery of excessive heat energy to a particular area.

Quasi-continuous Wave Lasers

Although these lasers have less vascular specificity, their use may be preferable in some patients because of the lack of postirradiation purpura produced. Thus, patients with discrete areas of facial telangiectasias (rather than diffuse) are often considered to be good treatment candidates for quasi-CW lasers.

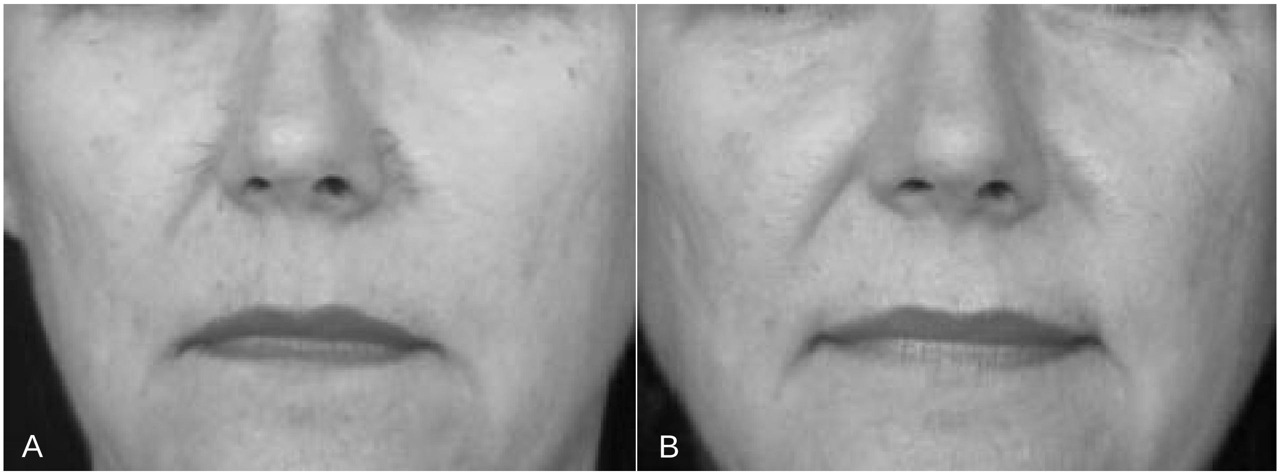

FIGURE 3. Linear telangiectasias in perinasal creases of 45-year-old woman (A) before and (B) 1 month after two treatments with quasi-continuous wave potassium titanyl phosphate (KTP) laser. (Any vascular-specific laser would be expected to effectively eliminate facial telangiectasias.)

Argon-pumped Tunable Dye Laser (577 nm, 585 nm). In essence, this laser differs from its CW predecessor by the ability of the light beam to be pulsed using a robotized scanner device. The appropriate technique requires the use of a spot size as small as 0.1 mm to trace each blood vessel. Good clinical results have been obtained using this system in telangiectasias and, to a lesser extent, port-wine stains.[61,62]

KTP Laser (532 nm). The KTP (Potassium Titanyl Phosphate) laser produces a 532 nm light beam in millisecond pulses that can be used to successfully treat telangiectasias despite its lower vascular-specificity. Using fluences of 15 to 20 J/cm^2 at these longer pulse durations effects elimination of telangiectasias without purpura in 1 to 3 treatment sessions (Fig 3).[63-65]

Copper Vapor or Copper Bromide Laser (578 nm). Clinical results using the copper vapor system for facial telangiectasias are comparable with those obtained with the argon-pumped tunable dye laser.[66,67] A small 150 μm spot is advanced along the vessels to effect blanching. Mild swelling and minimal crusting occurs within the irradiated areas with resolution within 1 week. Repeated treatments are delivered at bimonthly intervals.

Krypton Laser (568 nm). Small vascular lesions such as telangiectasias are generally treated using a 1 mm spot and 0.7 to 0.9 watts power with a 0.2 second pulse.[68] Similar to the other quasi-CW laser systems, mild cutaneous erythema and edema result from treatment.

LASERS FOR HYPERTROPHIC SCARS AND KELOIDS

Initially, various CW lasers (argon, Nd:YAG, carbon dioxide) were used to treat hypertrophic scars and keloids; however, recurrences within 2 years were uniformly observed.[69-75] In the past decade, the vascular-specific 585 nm pulsed dye laser has been shown in several studies to successfully treat the erythematous component of hypertrophic

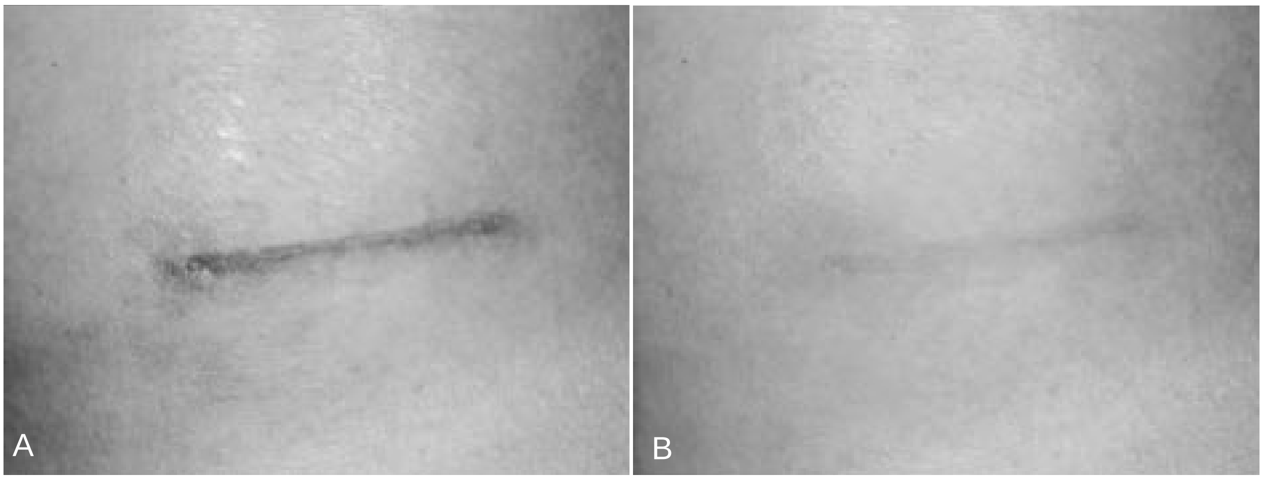

FIGURE 4. Hypertrophic breast augmentation scar (A) before and (B) 6 weeks after second 585 nm pulsed dye laser treatment.

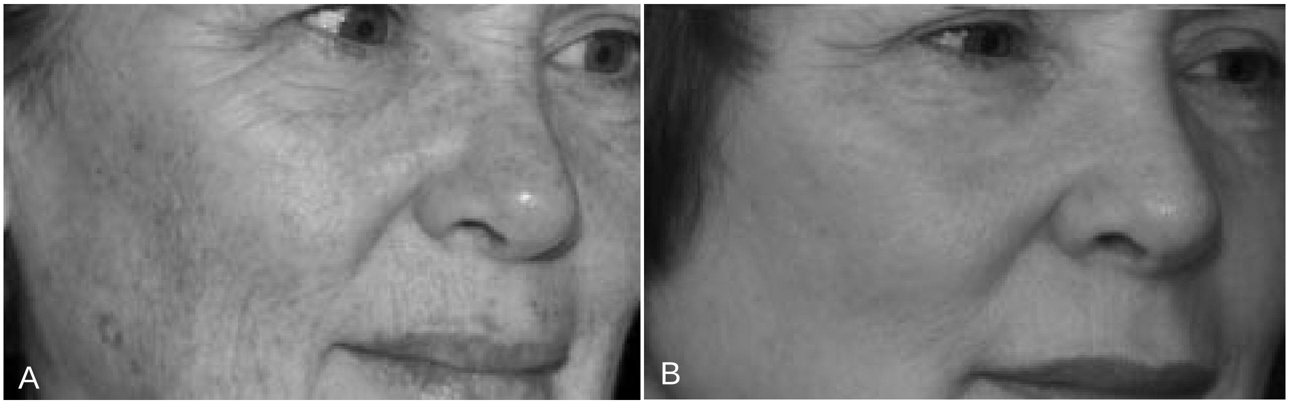

FIGURE 5. Photo-damaged skin with rhytides and dyspigmentation in 59-year-old woman (A) before and (B) 6 months after full face CO_2 laser resurfacing.

scars and keloids (Fig 4).[76-84] Furthermore, improvement has been observed in scar texture, pliability, thickness, and symptoms, after pulsed dye laser irradiation.[79,84] Selective destruction of the capillaries entrapped in these abnormally proliferative scars and an observed increase in tissue mast cell number in postlaser irradiated scars appear to influence collagen turnover and deposition.[79]

EPIDERMAL (KERATOTIC) AND DERMAL (PAPULAR) LESION LASERS

Various keratotic lesions, including verruca vulgaris, actinic cheilitis, seborrheic keratoses, and epidermal nevi can be treated with CO_2 laser vaporization.[85-87] Verrucae have also been successfully eliminated through selective destruction of the nurturing blood vessels by 585 nm pulsed dye laser irradiation.[88-90] Dermal lesions such as trichoepitheliomas, sebaceous hyperplasia, xanthelasma, and syringomas are most responsive to CO_2 laser vaporization.[87,91-93]

CUTANEOUS RESURFACING LASERS

Pulsed CO_2 (10,600 nm) and Erbium:YAG (2,940 nm)

Continuous wave CO_2 lasers had significant limitations due to heat transmission to non-target tissue, with subsequent scarring and hypopigmentation.[94] In recent years, noteworthy advances in CO_2 laser technology have now permitted successful skin resurfacing to be achieved without these undesirable complications.

Pulsed CO_2 lasers have been developed to achieve the desired amount of tissue ablation necessary for successful cutaneous resurfacing. High energy, short-pulsed, or scanned (<1 ms) CO_2 laser systems can deliver up to 500 mJ of energy per pulse to vaporize tissue so quickly and completely that transmission of heat to non-target tissues does not occur. These pulsed or scanned CO_2 lasers can be used to resurface skin with rhytides (Fig 5) and/or atrophic scars.[95-102] The most significant drawback to the use of these lasers is prolonged erythema (lasting 2 to 4 months).[103] Newer short-pulse erbium:YAG (2,940 nm) laser systems have recently entered the cutaneous resurfacing treatment arena and have been shown to produce less skin redness because of reduced residual thermal damage. Because of the limited thermal effect on tissue and decreased collagen contraction, however, the clinical results obtained with erbium:YAG laser resurfacing is often less dramatic than with the pulsed CO_2 systems.[104-106] The cutaneous resurfacing lasers can also be used in conjunction with blepharoplasties, facelifts, and hair transplantation to reduce intraoperative bleeding and postoperative recovery time.[107-111]

NEW TRENDS

Photodynamic therapy has been used to treat cutaneous malignancies and psoriasis unresponsive to conventional therapy. It involves using lasers in conjunction with exogenous photosensitizers.[112] Long-pulse ruby, alexandrite, and Nd:YAG lasers are being used to target terminal hair for the purpose of achieving prolonged hair removal after multiple successive laser sessions.[113-119] Early (erythematous) striae atrophicae have shown favorable clinical response to 585 nm pulsed dye laser irradiation when compared with CO_2 laser vaporization.[120,121] Infraorbital dark circles have been improved with the use of pigment-specific[122,123] and resurfacing lasers.[124] Photothermolysis of lower extremity telangiectasia is under investigation[125] and is already a useful adjunct to current sclerotherapy techniques.

A wide range of lasers is now available for dermatologic treatment. Future developments and advances in laser technology will continue to expand therapeutic options, improve clinical outcomes, reduce complications, and offer a more efficacious way of treating a variety of skin conditions.

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