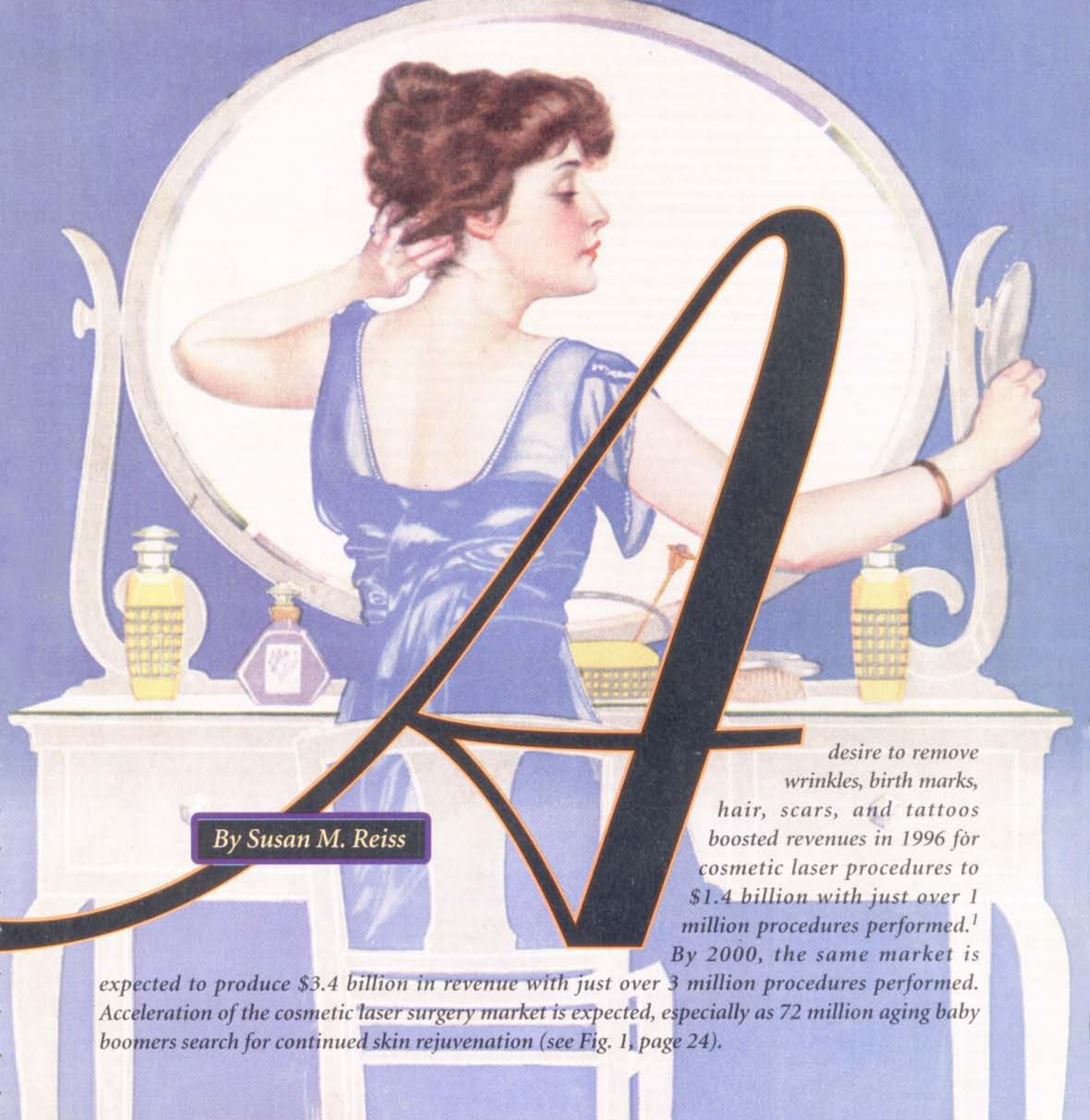
CO_2 and erbium laser systems are the current lasers of choice for skin resurfacing applications. But which is better and are there alternatives? Reiss addresses these questions, and looks at the needs—both in training and technological development—of this fast growing market.

Lasers: Magic Bullets of the Cosmetic Revolution?



By Susan M. Reiss

A desire to remove wrinkles, birth marks, hair, scars, and tattoos boosted revenues in 1996 for cosmetic laser procedures to \$1.4 billion with just over 1 million procedures performed.[1] By 2000, the same market is expected to produce \$3.4 billion in revenue with just over 3 million procedures performed. Acceleration of the cosmetic laser surgery market is expected, especially as 72 million aging baby boomers search for continued skin rejuvenation (see Fig. 1, page 24).

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Because skin types are affected differently by various lasers, patient

Prices for two of the most widely used laser systems—CO_2 and Er:YAG—range from $50,000 to $90,000; annual maintenance costs range between $5,000 and $20,000 per system. "We'd like lasers to be a magic bullet, but despite the fact that lasers are steadily moving forward, we're still in the realm of large, expensive devices," says Rox Anderson, research director at Massachusetts General Hospital's (MGH) Laser Center. Patients foot the bill for these systems because reimbursement by insurance companies is rare, except when the condition is deemed disfiguring or causes persistent discomfort.

Courtesy Tina Alster, M.D.

Figure 1. a) Photodamaged skin and b) after CO_2 resurfacing.

Courtesy Richard Fitzpatrick, M.D.

Figure 2. Both CO_2 and erbium lasers were used during the treatment session for this patient. The CO_2 laser is used to remove the epidermis and for thermal effects on collagen to achieve tightening of photodamaged skin. The erbium laser enables the physician to sculpt away surface irregularities secondary to photodamage, as well as for feathering of the periphery of the treatment area.

Courtesy Khalil Khatri, M.D.

Figure 3. a) Resurfacing patient (pretreatment). b) One-week postoperative. A CO_2 laser was used on the patient's right side, Er:YAG on the left. c) Six months postoperative. Despite more rapid healing on the erbium side, improvement is similar for both sides.

Which laser is best?

Preparing physicians to perform laser procedures goes beyond proper technique. Physicians must choose from an array of lasers and an array of claims made by their manufacturers. "There is confusion within the community because there are a lot of laser manufacturers producing similar lasers and some of the claims are partial truths," says Richard Fitzpatrick (a doctor of dermatology at Dermatology Associates of San Diego County Inc.).

Of chief concern among physicians is deciding which laser works best for a given procedure. For skin resurfacing applications, the current competing technologies are pulsed and scanned CO_2 and Er:YAG laser systems. Those interviewed for this article agree that the number of laser manufacturers with similar lasers presents some difficulty for physicians trying to select a laser or suite of lasers to use. "Clinical comparisons are the bottom line with regard to understanding how each laser performs," says MGH's Anderson. And although several head-to-head studies have been completed in the past two years comparing CO_2 and Er:YAG systems, those interviewed agree that physician experience, treatment application, and patient selection can alter clinical outcomes (see Fig. 2).

One study, discussed at the 1997 American Society for Laser Medicine and Surgery meeting, and conducted by Khalil Khatri and colleagues at the Wellman Laboratories of Photomedicine, compared a Er:YAG laser[2] and CO_2 (see Fig. 3). Twenty patients took part in the study in which one side of the face was treated with the CO_2 and the other with the erbium laser. Three passes of the CO_2 laser and seven passes of the erbium laser produced about an equal depth of tissue vaporization, namely 50–80 μm. Residual thermal damage on the erbium side was 0–20 μm, damage on the CO_2 side ranged between 80–150 μm. According to Anderson, who was a co-author on the study, regardless of the number of passes, the erbium laser produced more rapid re-epithelialization (new skin growth) and decreased erythema (redness) than the CO_2 laser. However, with an equal number of passes, the side treated with the CO_2 laser looked tighter and more wrinkle free than the erbium-treated side.

and laser selection are critical.

Anderson notes that because CO_2 lasers have historically been used to resurface skin in "really old, wrinkly people," and doctors got comfortable with the procedure, the CO_2 laser has never been tested in a gentle mode. "We need a study of young patients treated with low fluences for a real comparison with erbium," says Anderson.

Tina Alster, director of the Washington Institute of Dermatologic Laser Surgery, and Christopher Nanni, a doctor at the Institute, have also conducted a number of comparison studies. One study evaluated the histologic and clinical effects of four different CO_2 lasers used for skin resurfacing. They concluded that the Ultrapulse, Trupulse, FeatherTouch, and NovaPulse systems show variations in their clinical outcomes and histologic effects, but each can produce satisfactory clinical results.[3] Studies by Alster comparing six erbium lasers for skin resurfacing found no significant clinical differences between the Candela, ConBio, HGM, MDLT, SEO, and Sharplan lasers in terms of re-epithelialization rates, duration of redness, or clinical outcome.[4] In addition to comparison studies for skin resurfacing lasers, comparison studies are now emerging for lasers used to remove hair, tatoos, and spider veins[5–7] (see Fig. 4, page 26).

In the right hands

Physician training in laser surgery, overall, and cosmetic surgery, in particular, has become more extensive during the last five years. Dermatology residencies now require exposure to laser surgery, though this is only an introduction to the field. Various academies related to dermatology and cosmetic surgery also offer basic laser courses that include material on laser-tissue interaction as well as hands-on training. In addition, Harvard Medical School offers weekend courses through its Department of Continuing Education. Preceptorships with physicians skilled in laser surgery are now common. "In the best of all worlds, physicians should do a formal fellowship," says Tina Alster. "This allows physicians to see a wide range of patients with a variety of lesions, skin types, and skin responses, and to follow their responses post-operatatively." Because skin types are affected differently by various lasers, patient and laser selection are critical.

"Technique is everything," says Alster. "You want a little bit of residual thermal damage in tissue so that a tight collagen scaffold is effected. Skin redness shows active healing." But she adds that in the hands of an

New Opportunities for Optics

A new video camera that uses polarized light will help dermatologic surgeons visualize skin cancer margins that are not clinically visible (see Fig. 1). The goal of the system is to create an image based on light scattered from the top 200 µm of skin. "We're able to get a fingerprint that shows the signature of the ultrastructure of tissue," says Steven Jacques of the Oregon Medical Laser Center (OMLC), who along with Ken Lee, a doctor at Oregon Health Sciences University, developed the camera. Their work was presented at Photonics West in January.

The light source for the camera is incoherent white light polarized by a filter that obliquely illuminates a skin site. An optical flat on the skin surface provides optical coupling and a smooth surface so that specular reflectance from the glass/skin interface is reflected obliquely and misses the camera. Light scattered by the tissue is imaged by a camera that views the site through a polarization filter that can be aligned to collect light polarized either parallel or perpendicular relative to the source (see Fig. 2).

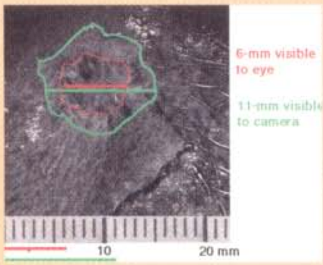

Figure 1. Using the polarized light, the camera expands the observable margins of cancer from 6 mm (detectable by the eye) to 11 mm. The camera could improve surgical excisions by reducing the need for costly follow-up surgery.

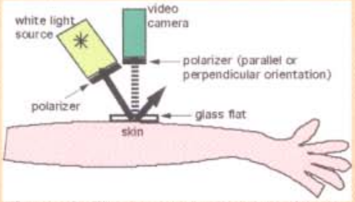

Figure 2. The prototype in clinical testing. The ratio of an image taken with parallel orientation and one taken with perpendicular orientation clarifies pigmented lesions allowing the doctor to view the underlying tissue structure.

Images are calculated pixel by pixel from the two acquired images, calculating the ratio of the difference of images by the sum of images. "The ratio cancels the melanin absorption and clarifies images of pigmented lesions enabling the doctor to view the underlying tissue structure," explains Jacques (see Fig. 3).

Researchers at Oregon Health Sciences University are using the camera to study skin cancer lesions in patients at the Veterans Administration Hospital in Portland, Ore.

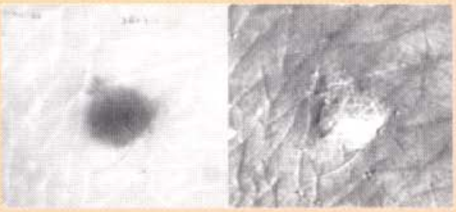

Figure 3. Normal image (left) and a polarized image (right) of a pigmented nevus. The nevus pigmentation disappears in the polarized image revealing an underlying structure.

> *"If a company is willing to put some money into this work, these issues will be resolved within a year."*

inexperienced practitioner, complications can be considerable. For patients who are scarred (see Fig. 5), corrective treatment can be provided.[8] "There are clearly risks, but these are minimal when surgery is performed by someone with lots of training," Alster notes.

Near-term outlook

Procedures

The next target for cosmetic surgery is collagen tightening. "Whether this can be done successfully has been the topic of debate," says Fitzpatrick. "There is a huge body of literature on the behavior of collagen when exposed to heat. The problem arises when confining the heat to a window of temperature without damaging the overlying epidermis." The issues of epidermal cooling and appropriate wavelength are still under investigation. Early work in this area used a 1.32 μm Nd:YAG laser, though Fitzpatrick suggests that wavelengths similar to those of holmium lasers should work. "If a company is willing to put some money into this work, these issues will be resolved within a year," Fitzpatrick contends. "It requires an intensive effort." Collagen tightening would be especially helpful on the arms and knees, which are difficult areas to treat.

Technologies

"What will make a difference is the penetration of semiconductor diode lasers and miniaturized solid-state lasers as pump sources into medical use. We're in transition right now," says Anderson. Potential applications for diode lasers include skin resurfacing and hair removal. "The problem with diode lasers is that they're not pulsed," explains Victor Ross, a staff physician and co-director of the laser section at the Naval Medical Center in San Diego. "Integrated rapid scanners could resolve this issue," he adds.

Because scarring and infection are the two biggest complications of skin resurfacing, Ross anticipates a greater investment over the next three to five years in improved wound dressings, biological response modifiers to accelerate healing, and additional research to understand the mechanisms of scarring. Efforts will continue to enhance cooling devices and to develop more flexible waveguides and more ergonomically adaptable scanners that will reduce user fatigue.

Another key to advancing dermatologic surgery is to make smart lasers, says Anderson. "This is nothing other than a technical challenge. The military makes use of 'smart' technology, but there is no use of it in medicine." Anderson defines "smart" as a laser that takes information in at the time of use and modifies output according to the tissue it encounters. "The only feedback mechanism we have right now is the physician. By providing tools that do what is humanly impossible, we can suck the vagueness and tedium out of many of these procedures," Anderson explains.

Moreover, a greater understanding of the primary processes of light and tissue interaction is needed. "We're just beginning to understand many issues such as laser generated shock waves," says Anderson.

Long-term outlook

As comparison work continues on CO_2 and erbium lasers, the U.S. Food and Drug Administration has approved the sealed TEA CO_2 laser, which its manufacturer, Argus Photonics Group, claims bridges the gap between CO_2 and erbium lasers, and costs under \$10,000. Howard Green, medical director for Argus Photonics Group, says bloodless ablation with the TEA CO_2 produces no visible char at 5 J/cm^2 with a top hat beam profile (see Fig. 6). The spot size of the TEA CO_2 reaches up to 7 × 7 mm

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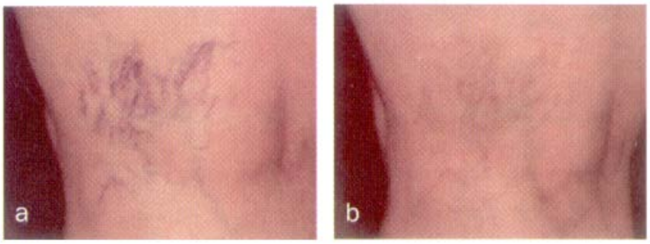
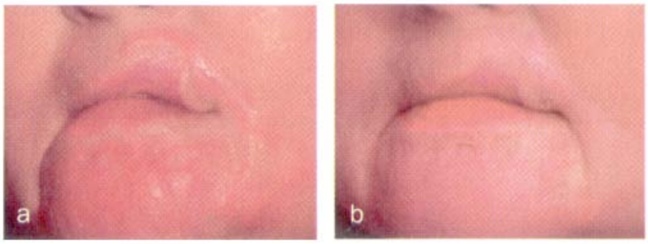


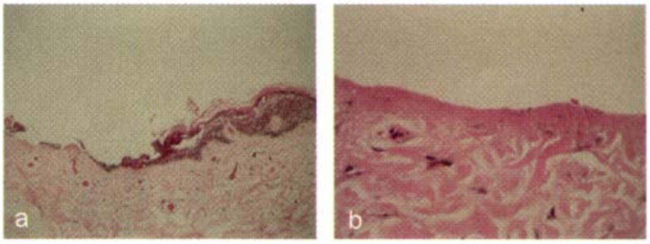
Courtesy Tina Alster, M.D.

Figure 4. a) Spider veins on legs and b) following sclerotherapy and "touch up" with laser treatment.



Courtesy Tina Alster, M.D.

Figure 5. a) Burn scars caused by poor CO_2 resurfacing technique and b) improvement after two treatments with a 585-nm pulsed dye laser.



Courtesy Argus Photonics Group.

Figure 6. a) Three pulses ablated 120–150 μm of tissue and induced a 50-μm zone of thermal damage (without saline debridement).
b) Ablated 150–200 μm of tissue and induced a 25-μm zone of thermal damage (with saline debridement).

correlation signal of a BBO crystal was registered. By comparison of the two autocorrelation functions, the decay time τ of the electronic excitation that resonantly enhances SHG was extracted. Extreme care was necessary to ensure identical, chirp-free light pulses in the signal and reference beam paths.

The experiments offer the following combination of advantages: the measurements are carried out under well-defined conditions, *i.e.*, in ultrahigh vacuum; particles of variable size can be prepared and thus femtosecond decay times determined as a function of cluster size; and fundamental radiation in resonance, as well as out of resonance, of surface plasmon excitation is applied. Conditions were verified experimentally by *in situ* measurement of the linear optical transmission spectra of the same clusters used for femtosecond SHG; and the cluster surface can be modified intentionally by chemisorption of oxygen. Two metals, sodium and potassium, were investigated.

The most important results can be summarized as follows. Chirp-free light pulses are an indispensable condition for the correct determination of ultrafast electronic decay times and extreme care is necessary to ensure identical chirp-free pulses in the signal and reference beam path. If chirp is introduced intentionally, the autocorrelation function broadens and thus pretend decay times that are too long. For both metals, the decay time was found to be $\tau \leq 5$ fs. This upper limit turns out to be independent of particle size and remains constant regardless of whether the fundamental (potassium) or second harmonic (sodium) light is in resonance with surface plasmon excitation. Also, the value of $\tau \leq 5$ fs does not change if the particle surface is modified by chemisorption of oxygen. Numerical simulations of the autocorrelation function indicate that the decay time could be longer due to the inhomogeneous broadening of the plasmon resonance.

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Lasers for cosmetic surgery

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with single pulse energies ranging from 500 mJ to 2.7 J. Peak power ranges from 500 KW to 2.7 MW with repetition rates from more than 4 Hz to 1 Hz.

Development of a single tunable laser that provides pulsed and continuous operation is the desire of many dermatologists, but they agree that technical hurdles including the loss of energy associated with changing wavelengths and the need to alternate between pulsed mode and continuous operation present challenges for this approach.

While the short-term effects of cosmetic laser surgery are dramatic, the long-term effects of laser surgery on aging skin are unknown. But as Victor Ross contends, "History is on our side. We've been doing dermabrasion for 40 years with no problem and the laser is just doing what other techniques such as chemical peels did. As a scientist, I don't think negative long-term effects will creep up on us like a monster."

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