Erythema After Cutaneous Laser Resurfacing
Using a Porcine Model

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Objectives: To measure and compare postoperative erythema after laser cutaneous resurfacing using 2 carbon dioxide laser systems and varying postoperative treatment methods.

Design: Carbon dioxide laser systems are used as cutaneous resurfacing tools. The continuous-wave lasers have been associated with postoperative erythema, but the short-pulsed lasers reportedly result in less postoperative erythema because of shorter pulse durations. Although subjective evaluations of results have been published, a side-by-side comparison with digital photography has not been performed. Furthermore, postoperative treatment varies among physicians, and objective data about this treatment are scarce.

Subjects: To compare postoperative erythema, we created 240 resurfacing wounds on 8 piglets with continuous-wave and short-pulsed lasers, using the manufacturers’ suggested settings. By using photography and computed color analysis, we measured the resultant erythema after 1, 3, and 5 laser passes at days 0, 1, 3, 5, 7, and 14. Tissue samples were obtained for histological analysis on days 0, 3, 7, and 14.

Intervention: We compared the resolution of erythema after postoperative treatment with petroleum jelly (Vaseline), a wound dressing (Vigilon), partially hydrogenated vegetable oil (Crisco), or a combination drug, bacitracin zinc–neomycin sulfate–polymyxin B sulfate on the wounds.

Results: The short-pulsed carbon dioxide laser resulted in an average of 22% less erythema compared with the continuous-wave laser ($P<.001$). No statistically significant difference in erythema was found among the postoperative treatment methods ($P>.10$).

Conclusions: Compared with the continuous-wave laser, the short-pulsed carbon dioxide laser results in less postoperative erythema. However, the type of postoperative treatment has little, if any, beneficial effect for reducing erythema.


To counteract the effects of aging and solar damage, physicians have used dermabrasion or chemical peels to reduce fine wrinkles on the face. A criticism of the use of dermabrasion and chemical peels is the lack of control over the depth of injury to the skin. Complications such as hypopigmentation and scarring occur when the injury is extended too deeply into the dermis. The carbon dioxide laser has been adapted as a cutaneous resurfacing tool to gain more control over the depth of injury and to avoid these complications. However, one particular concern has been the prolonged postoperative erythema associated with the use of the carbon dioxide laser resurfacing devices.1,2

The goal of any resurfacing technique is to remove the superficial epidermis and, depending on the desired depth of the injury, the papillary dermis. These changes in the dermis result in the clinical improvement of fine wrinkling. Histologically, skin that has been resurfaced demonstrates a thicker dermis with more parallel bands of collagen and less elastosis and perivascular inflammation. The healing process dictates the results. When the ablation is extended into the papillary dermis, the healing occurs by reorganization of collagenous matrices. However, when the ablation extends into the reticular dermis, excessive scarring occurs, which consists of disorganized thick bands of collagen.3 The carbon dioxide laser works by destroying the superficial layers of the skin and inducing changes in the papillary dermis, actions similar to those of dermabrasion and chemical peels. Early experience using the carbon dioxide laser as a resurfacing tool resulted in excessive thermal injury to the underlying der-
MATERIALS AND METHODS

We used a porcine model for human skin. Institutional guidelines for animal experimentation were followed. Piglets were anesthetized with halothane during treatment and image documentation. The skin was prepared by shaving and cleansing with saline immediately before resurfacing. A baseline photograph of the skin of each animal was obtained. Fifteen wounds were created on each side of the piglet with each laser using the 2 laser systems and typical clinical settings. A laser beam scanning device (Silktouch, Sharplan Lasers Inc, Allendale, NJ) with a 125-mm handpiece (200-µm beam) was coupled to a CW carbon dioxide laser (Sharplan 1060, Sharplan Lasers Inc) set to single, 8-W, 0.2-second pulses. The SP carbon dioxide laser (TruPulse, Tissue Technologies, Albuquerque, NM) was set to single, 200-mJ pulses with a 5-Hz repetition rate. The TruPulse spot size was 1.9 X 1.9 mm.

Linear wounds of equal surface area were created with 1, 3, or 5 passes of each laser. The wounds were gently débrided with a saline-soaked gauze sponge between passes. The wounds were then covered with 1 of 4 dressings or used as a control: (1) petroleum jelly (Vaseline, Chesebrough-Ponds USA Co International, Greenwich, Conn); (2) a combination drug, bacitracin zinc–neomycin sulfate–polymyxin B sulfate; (3) partially hydrogenated vegetable oil (Crisco, Procter & Gamble, Cincinnati, Ohio); and (4) a wound dressing (Vigilon, C.R. Bard Inc, Murray Hill, NJ). All wounds (including the control wounds) were covered with a transparent dressing (Opsite, Smith and Nephew, Memphis, Tenn) and wrapped with a bandage (Coban, 3M, St Paul, Minn) to prevent soiling of the wounds by the piglets. The wounds were photographed for color analysis at days 0, 1, 3, 5, 7, and 14 after laser resurfacing. Dressing changes were performed each time the wounds were photographed.

Each of the 8 piglets received 1 wound of each type and 1 of each of the treatments (2 lasers; 1, 3, and 5 passes; 5 different postoperative treatments) for a total of 30 test sites per piglet. On each of days 0, 3, 7, and 14, tissue samples were obtained from 2 different piglets for histological examination. Therefore, all histological analyses were performed on tissue samples from 2 different animals. The color analysis was averaged from 8 animals on the day of surgery; 6 animals on days 1 and 3; 4 animals on days 5 and 7; and 2 animals on day 14. The color analysis was also the average color intensity from approximately 2000 pixels from each digital photograph.

The tissue was stained with hematoxylin-eosin to examine the basic architecture of the wounds and to evaluate wound healing. The thermal injury patterns were assessed by using a hematoxylin-eosin stain and a Masson trichrome stain for collagen.

DIGITAL COLOR ANALYSIS

Photographic documentation was standardized throughout the experiment by using digitized photographs produced with a video camera (Ikegami MKC-301A, Ikegami, Tokyo, Japan) mounted on the side port of a surgical microscope with a 400-mm focal length lens (OPHI, Carl Zeiss Inc, Thornwood, NY). The camera was interfaced with the built-in video port of a microcomputer (Macintosh 840 AV, Apple Computer Inc, Cupertino, Calif). Images underwent digital color analysis using a software program (Adobe Photoshop 2.0, Adobe Systems Inc, Mountain view, Calif). A palette of a pink closely matching the erythema of the piglet skin was used as a standard. The palette controlled for any variations in lighting or data acquisition.

The software used for digital color analysis measures the relative amount of red, blue, and green of each wound captured in the digital image. The combination of all 3 colors is important in the perception of “redness.” The absolute values of red, blue, and green are entered into the formula:

\[ \frac{(Rw/Rp)}{((Bw/Bp)+(Gw/Gp))} \]

in which \(Rw\) is the amount of red in the wound; \(Rp\), the amount of red in the standard palette; \(Bw\), the amount of blue in the wound; \(Bp\), the amount of blue in the standard palette; \(Gw\), the amount of green in the wound; \(Gp\), the amount of green in the standard palette; \(Bwp\), the amount of blue in normal skin; \(Bwp\), the amount of blue in normal skin; and \(Gwp\), the amount of green in normal skin. The amount of each color varied from 0 to 255. As the formula indicates, the values are normalized to the standard color palette placed next to each image to control for technical discrepancies in obtaining the images.

STATISTICAL ANALYSIS

Statistical analysis was performed using factorial analysis of variance (ANOVA) using a Bonferroni-Dunn correction (Statview 4.0, Abacus Concepts, Berkeley, Calif). Statistical differences were determined by \(P\) values less than .05 after the correction. By using the factorial ANOVA, the influence of each variable can be assessed separately (eg, laser type, number of passes, and postoperative treatment). Statistical correlations with individual variables and multiple groupings of the variables are tested. Using 30 trials on each animal permitted us to study the various treatments, lasers, and number of passes. With the protocol described, we were able to measure statistically significant changes in redness greater than approximately 4%.

mis and dermal appendages with a high incidence of scarring and hypopigmentation. This excessive thermal injury can now be avoided. The technological advances in the newest laser systems have overcome these problems. The main focus of improvement has been limitation of the unwanted collateral thermal injury. The computerized scanning delivery systems and shorter pulse durations provide the desired limitation.

More than 5 J/cm² must be delivered in less than 1 millisecond to selectively ablate skin with minimal collateral thermal injury. The goal is to deliver high-power laser energy selectively to the skin in a time frame short enough to avoid collateral damage. This time frame is dictated by the thermal relaxation time of skin of approximately 700 microseconds. Two carbon dioxide laser systems that were developed to achieve these goals include a computerized, scanning, continuous-wave (CW) laser and a short-pulsed (SP) laser.

The CW laser has been associated with postoperative erythema, a condition unacceptable to patients al-

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ready concerned with their appearance. The CW laser is an otherwise standard carbon dioxide laser with a unique delivery mechanism. The articulated arm of the laser is fitted with a handpiece that is coupled to a computer-controlled aiming beam. The laser follows a collapsing spiral pattern, filling in a circular area within 200 milliseconds. The area varies depending on the size of the handpiece, with total spot sizes of 2.5 to 9 mm. The laser can deliver 5 to 20 J/cm². Because the laser is constantly moving, the tissue is not exposed to excessive thermal energy. By using a 3-mm handpiece at 7 W, a single pulse will result in an ablation depth of 70 µm with another 30 to 40 µm of thermal injury into the papillary dermis. Anecdotally, patients have less fine wrinkling and an improved overall appearance and do not experience prolonged erythema after treatment. Controlled objective measures of less erythema with the use of this laser for cutaneous resurfacing are not available. Therefore, we designed this study to compare the 2 laser systems with attention to the erythema noted after cutaneous resurfacing.

The study involves another area of controversy—the postoperative treatment of resurfaced wounds. Because the fresh wounds most closely resemble burn wounds, physicians typically treat the wounds with antibacterial topical agents and emollients. We studied the effects of 5 postoperative wound treatment methods on wound healing and postoperative erythema.

RESULTS

COLOR ANALYSIS

Compared with normal skin, the SP laser resulted in wounds with 19% more redness on the day of surgery. This increased to 24% on day 1 and 27% on day 3. On day 5, the relative erythema had decreased to 20% and to 11% on day 7. By day 14, the skin had returned to its baseline color. The CW laser resulted in 23% more redness on the day of surgery and 31% on day 1. This increased to a maximum of 32% on day 3 but decreased to 26% on day 5, 12% on day 7, and 4% on day 14 (Figure 1). These values included averaging all the wounds for each laser (P<.001).

When the percentage increase in redness is considered as a function of the number of passes, redness varied with the number of passes performed by the lasers (Figure 2). All wounds created with the SP laser demonstrated a 15% increase in redness after 1 pass. After 3 passes, a 19% increase in erythema was noted, and after 5 passes, a 21% increase was noted. The CW laser created wounds that had 22% more redness after 1 pass, 26% after 3 passes, and 25% after 5 passes (P<.001). Overall comparison of the wounds throughout the study showed that the SP laser created wounds that resulted in 22% less redness than the CW laser (P<.001).

When the postoperative treatment was studied, regardless of the laser used, the following changes in redness were noted (Figure 3). The control wounds were 22% more red on the day of surgery. This increased to 27% on day 1 and 35% on day 3. The redness lessened to 20% on day 5, 12% on day 7, and 0% on day 14. The Vaseline-treated wounds increased in redness to 22% on the day of surgery, 29% on day 1, and 30% on day 3. The increase was less pronounced on day 5, at 16%; on day...
7, it was 8%; and by day 14, the skin color had returned to baseline. Wounds treated with Vigilon dressings had a 19% increase in redness on the day of surgery; on day 1, it was 27%, and on day 3, 26%. On day 5, the redness was less intense, at 23%; on day 7, the redness was 14%; and by day 14, the skin color had returned to baseline. The Crisco-treated wounds were 20% more red on the day of surgery. The redness became more evident on day 1, at 28%; on day 3, it was 30%. The increase in redness was 27% on day 5, but it became less evident on day 7, at 12%; on day 14, it was 2%. Finally, the wounds treated with the combination drug were 20% more red on the day of surgery; on days 1 and 3, the redness was 28% and 29%, respectively. The redness of these wounds remained elevated, at 30% on day 5, but was less evident on day 7, at 13%; on day 14, the redness was 2%. We found no statistical differences among these postoperative treatment regimens (P > .096).

When comparing the erythema of the wounds among the 5 postoperative treatment methods as a function of the number of passes performed by each laser, the following results were calculated (Figure 4). After 1 pass, the wounds were 18% to 20% more red for each method of treatment. After 3 passes, the redness increased to 22% to 24% among all treatments. After 5 passes, the redness was 21% to 26% more than normal skin. Again, there were no statistical differences among the different treatment methods as a function of the number of passes (P = .95).

HISTOLOGICAL ANALYSIS

Tissue samples from the wounds were obtained from the piglets at days 0, 3, 7, and 14. The Masson trichrome and hematoxylin-eosin stains from the day of surgery revealed typical, acute, thermal injury patterns (Figure 5). The figure shows approximately 50 to 100 µm of thermal damage (darker stain) at the skin surface. The depth of the thermal damage did not change substantially with the increased number of laser passes; however, the depths of ablation varied with the number of passes. After 1 pass, the depths of ablation did not penetrate into the dermis. After 3 passes, the thermal injury reached the papillary dermis. The pattern of injury after 5 passes also demonstrated extension of the injury into the papillary dermis. The SP and CW lasers created similar injury patterns. Neither laser substantially penetrated the reticular dermis at the fluences tested.
The wounds treated with Crisco, Vigilon, and the combination drug crusted to an intermediate degree. The treatment of the wounds was relatively simple, with the exception of the Vigilon, which was awkward to apply.

Figure 6. Histological micrographs of skin samples 7 days after laser resurfacing. A, One pass of the short-pulsed (SP) laser. B, Three passes of the SP laser. C, Five passes of the SP laser. D, One pass of the continuous-wave (CW) laser. E, Three passes of the CW laser. F, Five passes of the CW laser (hematoxylin-eosin). The small bar in the upper right corner of each section represents 100 µm.

An ever-increasing desire to stay fit and look young has permeated our society. To keep up with these demands, physicians are resorting to more advanced techniques. In the past, dermabrasion and chemical peels shared the spotlight as the latest methods to treat fine wrinkles, acne, and other benign conditions of the face. Recently, the lay press has featured several new procedures available to treat the aging sun-damaged face; carbon dioxide laser resurfacing is one of these. The carbon dioxide lasers are advertised as a more precise method of removing the superficial layers of epidermis. Unlike chemical peels, carbon dioxide lasers ablate to the desired level of skin based on the power setting and the number of passes made. Chemical peels can vary in depth of treatment depending on the preoperative skin preparation; the type of skin of the patient; and the type, concentration, and duration of application of the peeling agent. These variables are more difficult to control for each patient undergoing chemical peels. Potential toxic effects of chemical peels are of no concern when using a laser.

The carbon dioxide laser offers other advantages over dermabrasion. The learning curve is steep for dermabrasion. Determining the depth of dermabrasion for effective treatment without causing a full-thickness skin loss is difficult in a bleeding surgical field. The carbon dioxide laser precisely removes the same amount of tissue without guessing. The physician must still judge the proper depth of ablation because skin thickness varies across the facial subunits. The use of lasers requires specific training, including safety for the patient, physician, and personnel. When used by a trained physician, the carbon dioxide laser is a safe and effective method of resurfacing the face.

Several carbon dioxide lasers are widely available. Deciding which carbon dioxide laser to use continues to be the subject of much controversy. Each manufacturer advertises its laser as the preferred tool for cutaneous resurfacing. Reports of randomized, double-blind, controlled studies are rare because of the nature of cosmetic procedures, ie, patients cannot be expected to undergo separate treatments on each side of the face. Thus, physicians should consider patient variability when comparing the results of treatment with different lasers.

Another issue subject to criticism is the photographic documentation presented by several authors and laser manufacturers. Most readers are aware of the difficulty in standardizing photographs among different patients who have received different treatments. Despite attempts to standardize the photographs, differences will exist with traditional photographic techniques. Comparison of the photographs taken by one author with those of another author is not valid. In an environment of increasing demand for precision, an accurate method of assessing results is needed.

To address these concerns, we compared the effects of 2 popular resurfacing carbon dioxide lasers on
postoperative erythema using a porcine model. The porcine model has been shown to be similar to human skin in hair growth, thickness, number of hair follicles, and sweat glands.

Because physicians differ in their opinions about the best postoperative treatment regimen for resurfaced wounds, we compared 5 methods of treatment to determine differences in their effects on wound healing and postoperative erythema. Attempts were made to standardize the methods to minimize variability in the subjects. By using digital color analysis, the subjective opinions about color changes were eliminated. In addition, differences in lighting, film exposure, and developing were avoided by using digital image acquisition with a control color pallet in each photograph.

When the postoperative erythema was measured, all wounds were calculated to have an increase in postoperative redness. The erythema peaked around postoperative day 3 and returned to baseline by day 14. Overall, the SP laser resulted in less erythema than did the CW laser. This finding correlates with previous reports of the depths of ablation caused by these lasers. Although we observed a trend toward less redness in the Vaseline- and Vigilon-treated wounds, the differences were not statistically significant. Therefore, postoperative wound treatment did not affect the degree of redness observed after resurfacing with these lasers. To our knowledge, no clinical studies have been published that have documented this observation. We cannot advocate the use of one postoperative treatment method over another. The choice should be made by the physician based on availability, cost, ease of use, anticipated patient adherence to the postoperative treatment regimen, and lack of adverse effects. Notably, we did not measure patient comfort in this study. All of these factors are important in the selection of the appropriate postoperative treatment.

Histological analysis did not reveal a significant difference in the thermal injury patterns of the 2 lasers; however, the analysis was limited to early changes. The hematoxylin-eosin and Masson trichrome stains failed to demonstrate why the SP laser wounds had less erythema. The underlying vasculature appeared the same for all the wounds. We noted no changes in the number of capillaries or the size of the vessels when we compared the 2 sets of wounds. Perhaps a more sensitive and specific stain for vascular tissue, such as a factor VIII stain, would have demonstrated a difference.

We noted that the postoperative erythema was a blanching erythema, indicating that the redness is vascular. This observation raises several questions. Why is the erythema more pronounced after ablation with the CW laser? Is it thermal injury? Is it a local tissue effect and vasodilation? Are there subtle temporary changes in the subdermal plexuses after cutaneous resurfacing? The effect is probably laser specific, because the duration of erythema is longer than that after dermabrasion or chemical peels. The exact mechanism is not known. Finally, piglet skin heals at a faster rate than does adult human skin. This may explain the shorter time required for the skin color to return to baseline in this study compared with the time required for human skin to return to the baseline color, which is usually 4 to 6 weeks after laser resurfacing.

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