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Infrared Imaging of CO₂ Laser Resurfacing

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ABSTRACT

The application of pulsed CO₂ lasers for skin resurfacing has been described by several authors^{1,2,3}. The procedure uses 30 μ s to 1 ms laser pulses with pulse energies from 100 - 600 mJ to ablate skin for the purpose of smoothing skin irregularities: that is, wrinkle removal. The CO₂ laser has been selected because it ablates a limited layer of tissue ($\sim$ 10 μ m at a radiant exposure of 5 J/cm²)⁴ and produce minimal thermal damage⁵.

The purpose of this study is to measure the surface temperature created during a resurfacing procedure and discuss the thermal implications of the measurements.

Keywords:

1. PROCEDURE

A Tissue Technologies Tru Pulse CO₂ laser provided pulse durations from 65 - 125 μ s and energy per pulse of 10 to 500 mJ. The laser spot was approximately a square of 0.3 cm x 0.3 cm, and the irradiance profile over the spot was relatively flat.

Temperatures were measured with an Inframetrics, Inc. Model 600L thermal camera that detected band limited (3 - 5 μ m) emissive power from the tissue. The camera was equipped with a 3x telescope, and a 9.5 inch focal distance close-up lens provided a view of approximately 3 cm x 3 cm.

Measurements were made in two modes. The image mode (60 fields per second) provide video image displays at 30 frames per second. Repeated scans across a single line were made in the line scan mode (125 μ s per scan). Limitations of thermal camera measurements are discussed by Torres *et al.*⁶.

In vivo temperatures were obtained from fuzzy rats. Animals were anesthetized with a mixture of ketamine and rompun (4:3 ratio) 0.1 mg/100g body weight. The hair on the back was removed with a creme depilatory.

Data were obtained using either 215 mJ, 100 μ s pulses or 350 mJ, 100 μ s pulses. Temperatures were measured for single spot exposures and for area scans. Single spots (0.3 cm x 0.3 cm) were radiated three times. Time was allowed between each exposure for the temperature to return to normal. Temperatures were measured using the line scan mode. Areas of 3 cm x 3 cm were scanned using a pulse repetition rate of 8 Hz. The laser beam was moved over the scan area one row at a time. The operator tried to minimize overlap between adjacent irradiation sites while maintaining a steady sweep of the laser beam. After completion of the area scan, the skin was cleaned by wiping with a saline-soaked gauze pad. Two additional scans were made without cleaning between scans, but with time for the tissue to return to normal temperature. Temperatures were measured using the image mode.

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The internal calibration of the camera adjusted for the telescope and close-up lens and an emissivity of 1.0 converted emissive power to temperature. Line scan data was digitized using the facility and software of Dr. Robert Flake. This software provided line temperatures as a function of time from which the transient decay of a single point could be measured.

The image mode provided gray scale images that were converted to temperature; individual frames were viewed to locate maximum temperatures during the laser scan of the 3 cm x 3 cm areas.

Tissue samples were sent to Dr. Sharon Thomsen for histologic analysis.

2. RESULTS

Examples of images of area scans captured during or immediately after a laser pulse are presented in Figure 1 for a 215 mJ pulse and in Figure 2 for a 350 mJ pulse. Temperature images are shown for the first, second and third passes of the laser beam. The non symmetric images are a result of creating an image from two fields that are separated by 33 ms. In addition, 125 μ s are required for each line in the scan. Measurements were made using a high and low range on the thermal camera to illustrate peak temperatures and the residual temperatures after the onset of the laser pulses. The average time for temperature to return to 10% of the peak temperature increase was 440 ± 360 ms.

An example of line scan data is presented in Figures 3 and 4. Figure 3 illustrates the relaxation in temperature of a single point. Line scan temperatures immediately after a laser pulse and 21 ms after the laser pulse are presented in Figure 4. The e^{-1} time constant was 20-40 ms.

The histological section of Figure 5 depicts the damage produced by two laser pulses of 215 mJ per pulse delivered in 100 μ s. Note disruption of the epidermis and 20-30 μ m of distinct thermal damage in the dermis.

3. DISCUSSION

The ablation of skin with CO₂ laser pulses was described in detail by Walsh and Deutsch using a 2 μ s pulse duration⁴. The mass of tissue removed per pulse as a function of radiant exposure [J/cm²] is given in Figure 6. Their figure has been modified to give ablation depth assuming a tissue density of 1 g/cm³.

Given the 0.3 cm x 0.3 cm laser spots, the peak energy of 215 mJ and 350 mJ corresponds to radiant exposure of 2.4 J/cm² and 3.9 J/cm². From Figure 6, the expected depth of ablation per pulse is only 4-6 μ m which is consistent with the histological section of Figure 5. The reported removal of tissue to a depth of 60 μ m with one pass of the laser beam cannot be due only to ablation.

The peak temperature presented in Figures 1 and 2 confirm that temperatures well over 100°C are associated with laser ablation. The increase in peak temperature during the second and third passes suggest either an increase in the absorption coefficient or a decrease in thermal conductivity. Also, as expected, increased temperatures were associated with increased pulse energy (compare Figures 1 and 2).

Decay times are much larger during scans where superposition of temperatures are likely to occur. Undoubtedly this superposition leads to high peak temperatures seen in Figures 1 and 2. The slow decay of temperature is evident in the low range temperature of Figures 1 and 2, where up to three distinct residual temperature images can be seen. The time between pulses is 125 ms, so the regions of increased temperature are seen because of laser pulses that occurred 250 ms in the past.

Superposition increases the volume of tissue heated and the effective diffusion times. It is obvious from the data that the 1 ms diffusion times associated with the penetration depth of the 1064 nm light must be viewed with extreme caution. Although the pulse durations are considered to be in the thermal confinement zone, measurable heat conduction begins within 50 μ s; that is, actually during the laser pulse⁷.

Figure 1. Thermal images captured during or immediately after a laser pulse, during CO₂ laser skin resurfacing. Laser pulse energy 215 mJ, pulse duration 100 μ s, pulse repetition rate 8 Hz. Large thermal camera temperature range, showing peak temperatures during first pass (a), second pass (b), and third pass (c). Small thermal camera temperature range, showing residual temperatures during first pass (d), second pass (e) and third pass (f).

Figure 2. Thermal images captured during or immediately after a laser pulse, during CO₂ laser skin resurfacing. Laser pulse energy 350 mJ, pulse duration 100 μ s, pulse repetition rate 8 Hz. Large thermal camera temperature range, shaving peak temperatures during first pass (a), second pass (b), and third pass (c). Small thermal camera temperature range, showing residual temperatures during first pass (d), second pass (e) and third pass (f).

Figure 3. Relaxation temperature profile for a CO₂ laser pulse on *in vivo* rat skin. Laser parameters: 215 mJ/pulse, 100 μ s pulse width.

Figure 4. Line scan temperature of a laser spot (a) immediately after the laser pulse and (b) 21 ms after the laser pulse. Laser parameters: 215 mJ/pulse, 100 μ s pulse width.

Figure 5. Histological section of rat skin (40x) after two pulses of 100 μ s, 215 mJ/pulse CO₂ laser radiation 93 mm x 3 mm spot). Note destruction of epidermis.

Pulse duration: 2 μ s

4. CONCLUSIONS

1. Peak temperatures exceed 100°C and increase with pulse energy and with the number of laser pulses.
2. Relaxation times are on the order at 20-40 ms for the e^{-1} time and 300 ms to reach 10% of the peak temperatures.

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REFERENCES

1. Hruza, GJ, Laser skin resurfacing, *Arch Dermatol*, 132:451-455, 1996.
2. Fitzpatrick, RD, MP Goldman, Advances in carbon dioxide laser surgery, *Clinics in Dermatol*, 13:35-47, 1995.
3. Fitzpatrick, RE, MP Goldman, NM Satur, WD Tope, Pulsed carbon dioxide laser resurfacing of photoaged facial skin, *Arch Dermatol*, 132:395-402, 1996.
4. Walsh, JT and TF Deutsch, Pulsed CO₂ laser tissue ablation: measurement of the ablation rate, *Lasers Surg Med*, 8:264-275, 1988.
5. Ross, EV, Y Domankevitz, M Skrobal, RR Anderson, Effects of CO₂ laser pulse duration in ablation and residual thermal damage: implications for skin resurfacing, *Lasers Surg Med*, 19:123-129, 1996.
6. Torres, JH, TA Springer, AJ Welch, JA Pearce, Limitations of thermal camera in measuring surface temperature of laser irradiated tissues, *Lasers Surg. Med*, 10:510-523, 1990.
7. van Gemert, MJC, AJ Welch, Time Constants in thermal laser medicine, *Lasers Surg Med*, 9:405-421, 1989.