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Incision Properties and Thermal Effects of CO2 Lasers in Soft Tissue

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ABSTRACT

Thermal and histological events resulting from soft tissue incision using CO2 lasers at 9.3u or 10.6u, fitted with a hollow wave guide or an articulated arm delivery system respectively, were investigated. In 9 fresh pig's mandibles, standardized incisions 3cm in length were made in the oral mucosa. Incisions were performed in the Cw mode at 1W, 4W and 12W. Thermal events were measured in adjacent soft tissues using thermocouples. Incisions were dissected out, fixed, embedded in paraffin wax, sectioned and stained with Serius Red. The Student's t-test for paired data was used to compare zones of necrosis, zones of necrosis, zones of collagen damage and thermal events. No significant temperature rise was measured during irradiation at any timepoints or power settings ($p<0.05$). Results were very similar for the two lasers with significantly different results obtained only at the 12W setting ($p<0.05$). Vertical incision depths and horizontal incision widths did not differ significantly ($p<0.0001$) at 12W and 4W. Horizontal and vertical zones of necrosis did not differ significantly ($p<0.0001$) either between the two lasers at 12W and 4W. Thus the thermal and histological events occurring during soft tissue incision were similar using these two lasers, despite the difference in wavelength and delivery system.

KEY WORDS

CO2 laser, soft tissue, thermal effects, thermal damage

1. INTRODUCTION

CO2 lasers have been utilized successfully for soft tissue surgery in the head and neck region for over 25 years. Clinical and laboratory investigations have consistently confirmed the advantages of this tool: precision, minimal intraoperative hemorrhage, sterilization of the surgical area and healing with minimal scarring, decreased postoperative pain and swelling (1-5). Areas of routine laser use include frenectomies, periodontal surgery, tumor resections and excision of lesions such as hyperplasia, papillomas, hemangiomas, lymphangiomas and mucoceles.

The CO2 laser emits light energy which is strongly absorbed by water, and therefore also by tissues with a high water content, such as the oral soft tissues. The absorbed energy causes vaporization of the intra- and extra cellular fluid and destruction of the cell membranes (6,7).

The exact nature and extent of the laser effect on soft tissue is governed by several factors. These include the total amount of energy delivered to the tissues over the entire period of irradiation as well as power levels. A unit of energy delivered over a very short period of time will have a greater effect than that same unit of energy delivered over a long time period. Spot size of the light beam used is also important. A unit of power or energy delivered over a large area by a large spot size will have milder effects than the same power or energy focused into a small spot size.

Structures directly adjacent to the area of vaporization demonstrate a range of thermal effects, depending on their proximity to the irradiation site and their optical properties. These marginal thermal interactions can range from mere transient heating to protein denaturation, water evaporation or even carbonization and burning.

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One characteristic difference between a laser and a scalpel cut is the generation of a coagulated tissue layer along the walls of the laser incision. This zone of thermal damage to adjacent structures should ideally be kept to a minimum, as it may impede wound healing, graft take and reduce tensile strength, especially if it is extensive. Furthermore, deeply penetrating laser-induced temperature increases can threaten the vitality of adjoining structures such as teeth, pulp or periodontium.

In the CO2 lasers traditionally available to clinical dentistry, light at 10.6u is delivered by means of an articulated arm and a handpiece to the surgical site. As the articulated arm configuration consisting of hollow, rigid tubes linked by joints can be cumbersome when working intra-orally, various alternative delivery systems, usually in the form of hollow wave guides, are now becoming available. Hollow wave guides, flexible or semi-flexible fibers used to conduct the laser beam often provide better maneuverability of the delivery system. Recently, CO2 lasers that deliver light in the 9.3μm region of the infrared spectrum have also been developed for clinical use. 9.3 μm better matches the absorption characteristics of hydroxy-apatite, providing improved ablation characteristics in hard tissues and consequently, greater protection for pulpal tissues. Technological advances have now allowed manufacture of a coherent beam delivery system for this wavelength.

It was the aim of this investigation to determine thermal events and soft tissue damage resulting from standardized laser incision using 2 different CO2 lasers: one emitting at 9.3μm via a hollow wave guide delivery system, the other at 10.6 μm via an articulated arm delivery system.

2. MATERIALS AND METHODS

In this investigation, 9 fresh pig's mandibles were used not more than 6 hours after the animal's demise. The mandibles were cooled until one hour before use, then returned to room temperature.

Using a laser, standardized incisions 3 cm in length were made in the oral mucosa, parallel to the border of the mandible, 5 mm below the gingival margin. To standardize the incision length, a template was positioned 3 mm below the planned incision site during the performance of each incision. A total of 20 incisions were made: a minimum of 3 per parameter with each laser type, whereby one of these incisions was performed in the anterior third of the mandible, the second in the middle third and the final incision in the posterior third. Two different CO2 lasers were used: one emitted at 9.3μm, the other at 10.6μm.

Prior to laser irradiation, a copper-constant thermocouple Philipe Type K with 0.25 mm diameter and a 63% response time of 7 ms was inserted into the soft tissue, directly below its surface and halfway (1.5cm) along the length of the incision. Laterally, the thermocouple was positioned at a distance of 1mm plus one half of the spot size from the incision line. Thus, for laser A, the thermocouple was located 1.12mm lateral to the line of incision; for laser B it was positioned 1.11 mm laterally.

2.1. Laser parameters

Laser A (Medical Optics Inc.) emitted at 9.3μm, the light being delivered via a coherent hollow wave-guide and a focusing handpiece. Spot size measured 250u. Laser B (Sharplan) emitted at 10.6u via an articulated arm beam delivery system and a focusing handpiece. Spot size measured 220u. All lasers were set to the continuous wave mode. Beam characteristics for each laser were calibrated by one laser engineer to conform to manufacturer's specifications, directly prior to this investigation. Spot sizes were measured and documented using photographic paper prior to each irradiation. Distance from the point of emission of laser light to the tissues was standardized by using a jig. Duration of irradiation for each incision measured 4s and was timed using a stop watch.

Actual power levels emitted were 1W, 4W and 12W. A PRJ-M power meter (Gentec) was used to determine actual values directly prior to each laser incision. These specific power levels were selected as they represent the range of minimum to maximum available in many clinical devices.

Within 3 minutes of irradiation, incisions were dissected out with a margin exceeding 5mm and divided into 3 sections using a scalpel. These tissue samples were fixed directly in 10% neutral buffered formalin and stored in buffered solution under refrigeration until embedded in paraffin wax. A total of 54 wax blocks was prepared. 6 micron wax sections were cut routinely and stained with Serius Red. A minimum of 3 slices from each block were used to obtain 10 slides per incision site, i.e. 30 slides per laser parameter. From each slide a measurement was made by the same blinded investigator of depth and width of adjacent tissue damage. A photographic record was made of the results.

The Student's t-test for paired data was used to compare zones of vaporization, zones of tissue damage and thermal events.

3. RESULTS

3.1. Thermal events

Figs. 1-4 depict thermal events and standard deviations during laser irradiation at 1, 4 and 12 W.

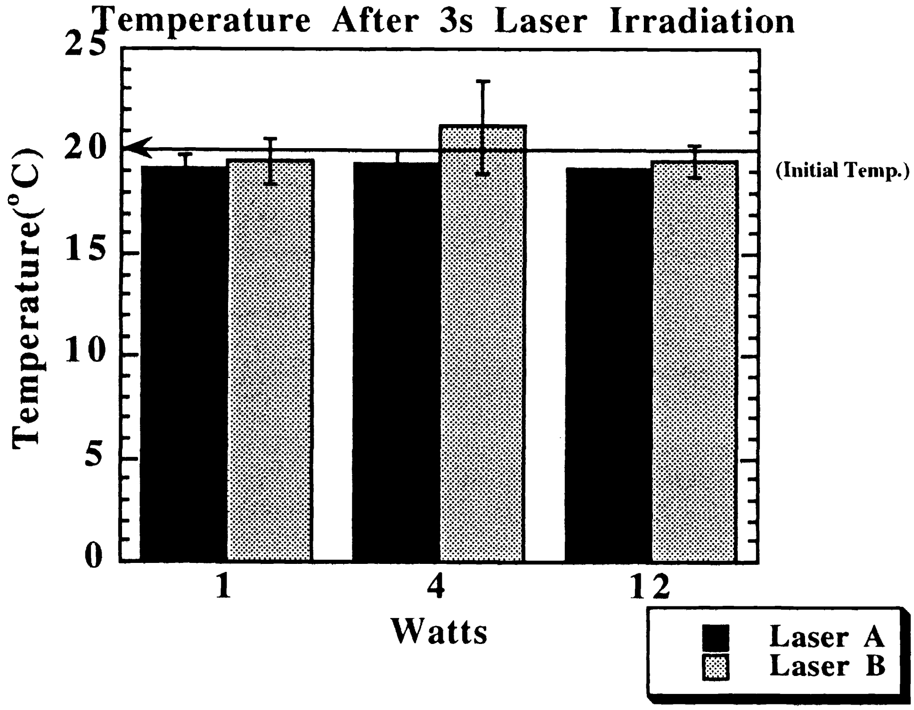

Fig. 1: Temperature after 3s laser irradiation. S.D. is depicted when greater than zero.

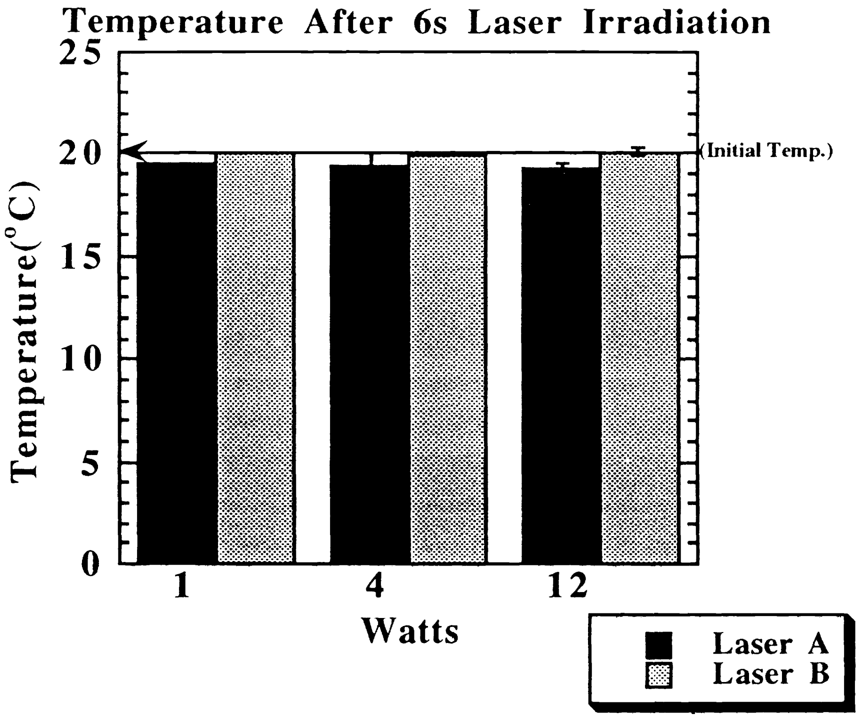

Fig. 2: Temperature after 6s laser irradiation. S.D. is depicted when greater than zero.

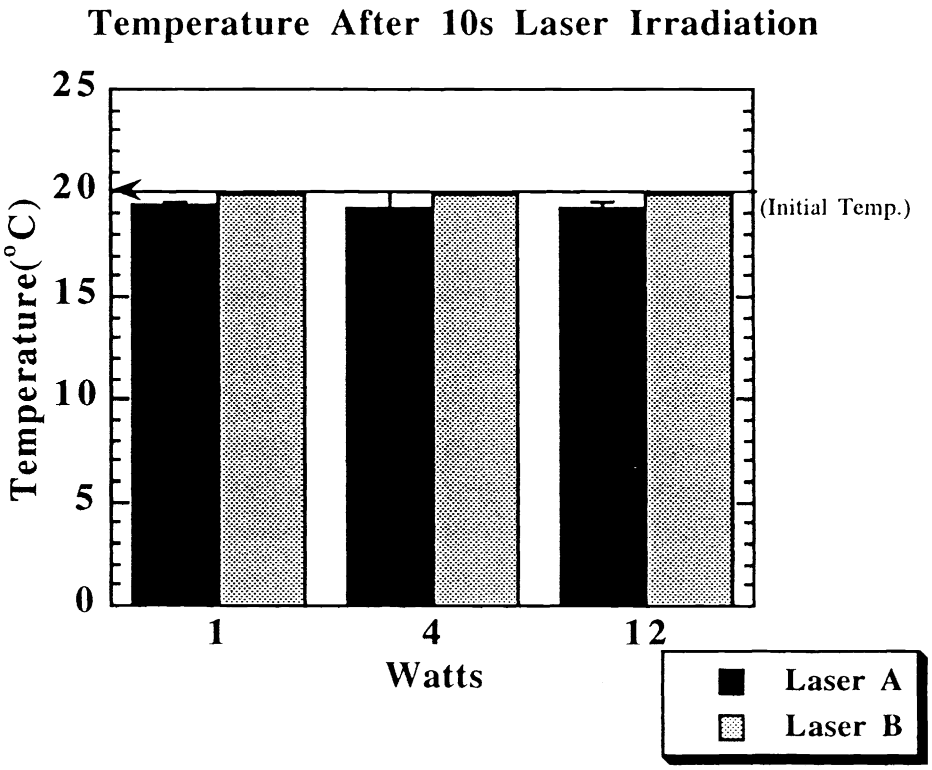

Fig. 3: Temperature after 10s laser irradiation. S.D. is depicted when greater than zero.

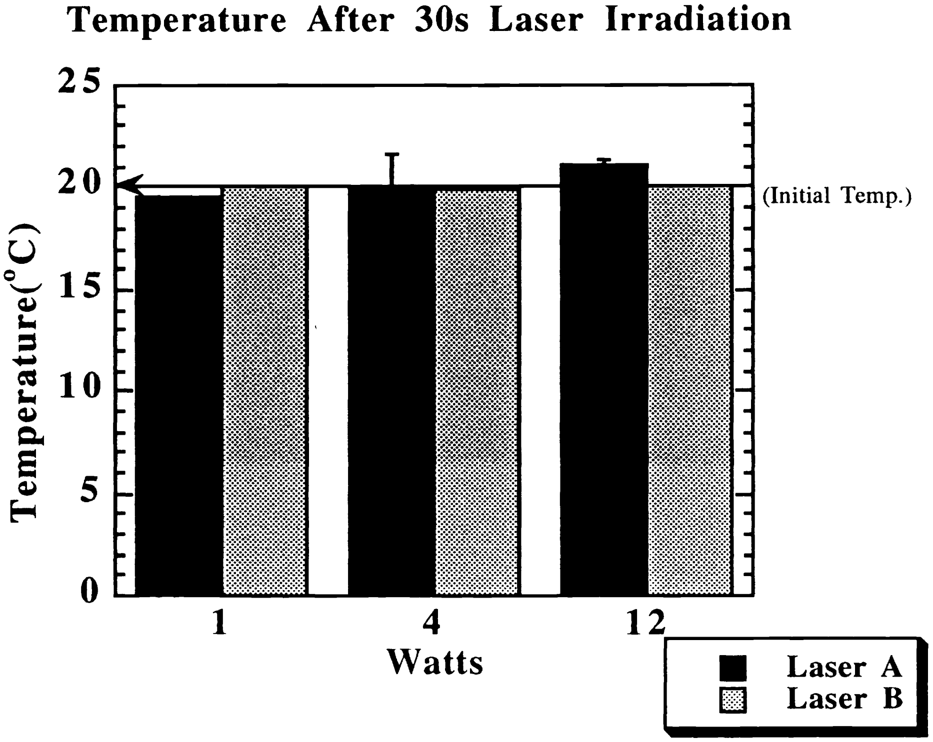

Fig. 4: Temperature after 30s laser irradiation. S.D. is depicted when greater than zero.

3.1.1 Thermal events during laser irradiation

During irradiation with lasers A and B, no significant temperature rise was measured during irradiation at any timepoints or power settings ($p<0.05$).

3.1.2 Comparison between laser types

Results were very similar for lasers A and B, with significantly different results ($p<0.05$) obtained only at the 12W setting.

3.2. Histological Data

Figs. 5-6 represent the extent of vertical and horizontal tissue damage adjacent to the laser incision. These measurements did not differ significantly ($p<0.0001$) between lasers A and B at 12W and 4W. As no clear incising effect was obtained with device B at 1W, no useful comparison was possible at this power setting.

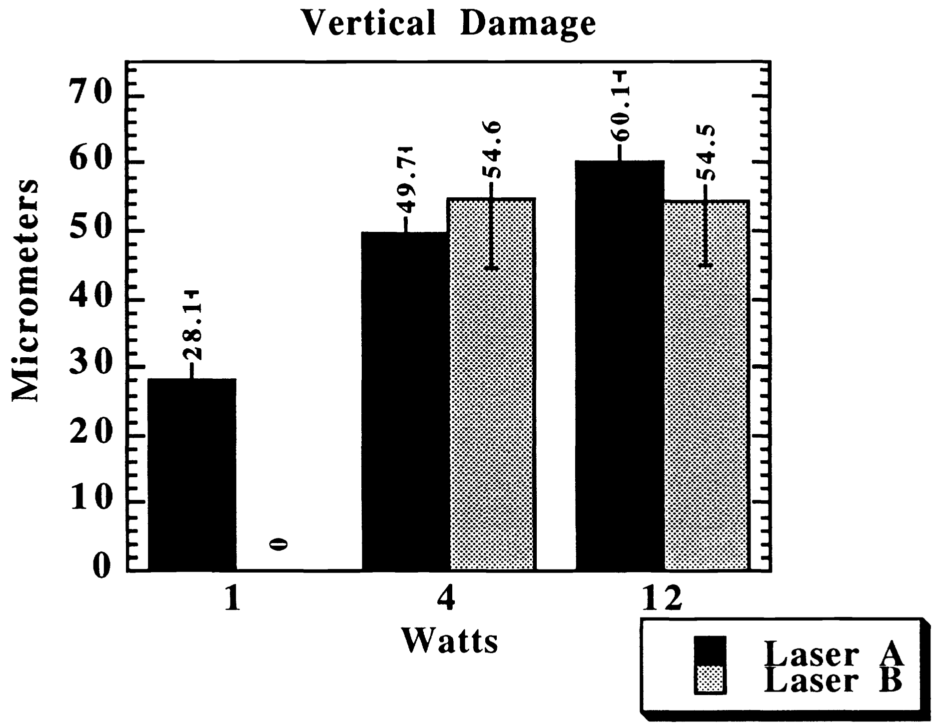

Fig. 5: Vertical damage at 1, 4 and 12W. No values are plotted for the Sharplan laser at 1W, as no incision resulted from irradiation at this parameter. S.D. is depicted when greater than zero.

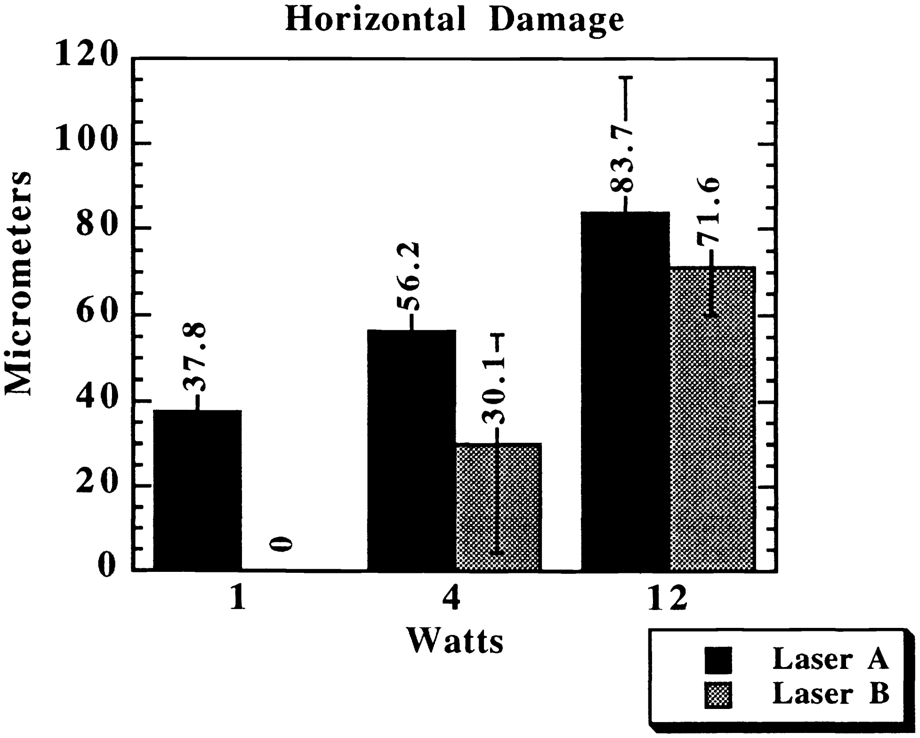

Fig. 6: Horizontal damage at 1, 4 and 12W. No values are plotted for the Sharplan laser at 1W, as no incision resulted from irradiation at this parameter. S.D. is depicted when greater than zero.

4. DISCUSSION

Several authors have conducted investigations comparing the histological and thermal effects of lasers vs. scalpels, or of lasers vs electrosurgery. Obviously, scalpels do not cause thermal necrosis, but they also fail to provide hemostasis, bacterial elimination and contact-free incision. Several authors report zones of thermal damage 3-5 times wider after electrocautery use than after CO2 laser use (8-12).

Studies have also been published regarding laser effects on soft tissues at various wavelengths and parameters. Of the clinically common dental lasers, the CO2 laser (at 10.6μ) usually produces narrower zones of tissue damage in soft tissues than the Nd:YAG, due to the greater absorption of CO2 light by soft tissues (13-15). However, little information is available comparing the soft tissue effects of continuous-wave CO2 lasers at 9.3u and at 10.6u.

During irradiation with lasers A and B, no significant temperature rises were measured in the soft tissues directly adjacent to the incision site, at a distance of approximately 1mm from the margin of the actual incision. This result is in agreement with many studies undertaken at 10.6u which report an average zone of damage after laser incision in soft tissues of <0.6mm (15-19). The results from this study indicate that the danger of thermal damage to adjacent structures during laser incision of soft tissues at 9.3 or 10.6u at the parameters investigated is minimal unless the adjacent structures are directly impacted by the laser beam. This finding is directly relevant to clinical dentistry, because of concerns regarding possible damage to neighboring structures such as teeth or bone during soft tissue laser surgery. In this situation the use of the 9.3μ wavelength may be particularly favorable, due to its greater absorption by hydroxyapatite, which should serve to reduce the possibility of pulpal damage by inadvertent laser irradiation.

Thermal results from lasers A and B did not differ significantly at comparable parameters except at all time-points using 12W. As the absorption of light in water at these two wavelengths is almost identical, and absorption characteristics in soft tissues resemble to a great extent those in water, due to high soft tissue water content, these results should be similar. Furthermore, both lasers A and B beam profiles are monotonic decreasing; gaussian or gaussian-like. Both lasers have coherent delivery systems and focusing handpieces. The differences at 12W were barely significant, and can probably be attributed to variations associated with the different beam delivery systems, which become increasingly significant at higher power levels.

Although the temperature increases measured in the course of this study were generally small, several additional factors should be taken into account when transposing our data to the clinical situation. Temperature measurement was performed using thermocouples, which were placed approximately 1 mm from the lateral margin of the incision site. Absolutely reproducible and precise location of the thermocouples with regard to the incision site and beam delivery was difficult, and yet it is directly relevant to the results obtained. More extensive investigations need to be performed using non-invasive devices located external to the tissues under investigation such as thermal cameras detecting within the IR range. Such studies are currently being undertaken by our group. Furthermore, maximum duration of irradiation in this study measured 30s. In the clinical situation, irradiation times may well be significantly longer, which can give rise to greater temperature increases than those measured in this study. In order to avoid this complication, use of short-duration, high power pulses with adequate pulse intervals is often preferable, providing good incision characteristics with greatly diminished heat accumulation and thermal effects as required in the clinical setting. It is for this reason that most lasers (including those investigated in this study) offer a range of pulse choices.

In this study we chose to use simple, non-pulsed parameters over a relatively short period of time to provide basic, widely applicable information on the characteristics of the lasers under investigation. The data will be used as a basis for further studies more directly related to the clinical situation.

Examination of histological data revealed little difference between lasers A and B. The discrepancies which were apparent between lasers at comparable settings are again linked to differing optics/beam characteristics incorporated into the laser devices, as described earlier in this discussion.

It is often stated that histologically evident effects of the CO2 laser extend approximately 60u into soft tissues (19). Thus our results at 10.6 and at 9.3u fall well within the range of previously reported histological effects. Although it is true that 99% of the laser light is absorbed within 60u, the zones of vaporization and damage from heat conduction will depend directly on the laser parameters used. Factors include energy density, constant/pulsed mode, pulse durations/intervals and exposure times. When we refer to the physics of vaporization applications of the CO2 laser we see that in order to vaporize a given volume of tissue, the energy necessary is a product of power multiplied by time. Thus the use of high powers by the surgeon results in rapid and effective vaporization along the incision line. However, use of high power densities in a continuous wave mode can lead to accumulation of heat and thermal damage to adjacent structures (20). In our investigation we did, indeed, observe a trend of greater damage to lateral tissues at higher power levels using the constant wave mode. This effect may be put to good use, for example, to enhance thermo-coagulation to achieve hemostasis and provide a bloodless surgical field. However, in general, for cutting without coagulation, very short pulses at the highest power density that can be controlled should be applied for the shortest time possible during incision of soft tissues to achieve the desired result with the least risk of unwanted thermal damage. Other authors have demonstrated that use of a superpulsed mode, based on the principles of high irradiance with short duration pulses and adequate pulse intervals will reduce thermal necrosis by a factor of 2 or more (16, 21).

In summary, this study determined thermal and histological events resulting from soft tissue incision using CO2 lasers at 9.3u or 10.6u, fitted with a hollow wave guide or an articulated arm beam delivery system respectively. Thermal and histological effects were related to parameters used and beam characteristics, rather than wavelength. Clinically, these results are significant in demonstrating that many variables are involved in determining the surgical characteristics of any laser. Thus it is important that all parameters be taken into consideration when using lasers as surgical tools, to ensure predictability, parity and consistency of results.

5. ACKNOWLEDGEMENTS

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