Thermal Changes in Endosseous Root-Form Implants as a Result of CO_2 Laser Application: An In Vitro and In Vivo Study

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Carbon dioxide (CO_2) laser surgery is advantageous in current clinical situations. The controlled and precise destruction of target tissue has made it a recommended procedure in intraoral surgery. Implant surgery demands minimal thermal changes in bone surrounding the implant. In this experimental study, different types of implants were placed in vitro in the mandible of a pig and in vivo in the mandibles of two dogs. In continuous mode, 4 and 6 watts, and in repeated pulse, 5 and 8 watts, for 2, 4, and 5 seconds, the CO_2 laser contacted several places around and on the implants. Temperature changes were measured at the implant-bone junction. The results showed that the CO_2 laser produced minimal temperature changes in the continuous mode power setting at less than 4 watts and in the repeated pulse, 0.05 second-interval power setting at less than 8 watts.
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Key words: CO_2 laser, endosseous implant, thermal changes

Endosseous root-form titanium implants are widely used in dentistry. Placement of implants at temperatures below 47°C causes no damage to the surrounding bone.[1] The second-stage exposure technique is critical to the long-term success of any implant. Under local anesthesia and using a scalpel, an incision is made on the crest, a full-thickness flap is reflected, and the implant cover screws are exposed. An alternative method of implant exposure involves use of the carbon dioxide (CO_2) laser to excise the soft tissues covering the implant.

The first report of CO_2 surgery appeared in the dental literature in 1979.[2] Since then, developments in oral soft tissue lesion excision, osteosurgery, and malignant tumor surgery have been reported.[3,4] In oral and maxillofacial surgery, the CO_2 laser has been shown to offer several advantages over other surgical instruments.[5–7]

The CO_2 laser beam has a wavelength of 10.6 µm, which is well-absorbed by water and, consequently, by tissues with a high water content such as the oral soft tissues. The absorbed energy causes vaporization of the intracellular and extracellular fluid and destruction of the cell membranes.[3] The CO_2 laser can be used in three ways: *(1)* with a focused beam, the laser is used as a "light knife" to perform hemostatic incisions; *(2)* with a defocused beam, the laser can be used for vaporization and debulking of tissue; and *(3)* with the SwiftLase, a CO_2 laser accessory for rapid scanning of the laser beam on tissue, it can be used to create a wide, shallow, char-free treatment site by precisely controlling ablation depth without causing residual thermal damage to tissues.[8,9]

For soft tissue lesions in the oral cavity, CO_2 laser surgery accomplishes noncontact hemostatic surgery and decreases postoperative edema and pain.[10–12]

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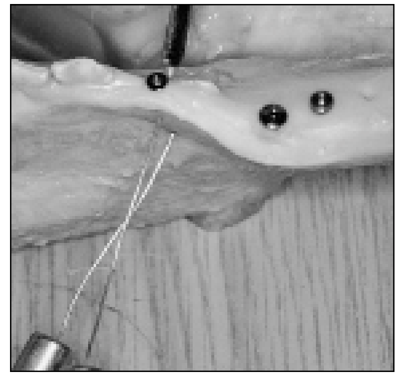

Fig 1 *(Left)* Six implants placed in a pig mandible; holes are drilled in the buccal bone.

Fig 2 *(Right)* Pig mandible. The handpiece of CO_2 laser beam hits the gingiva. Two thermocouplers are connected to the implant-bone junction on the buccal surface.

Most of the CO_2 energy, which is focused on the gingival tissue containing a large amount of water, is totally absorbed. But when the CO_2 laser beam hits a metallic object, such as a titanium implant cover screw, it reflects from its surface. In previous in vitro studies, the heat generated after CO_2 laser beam application on a titanium implant was investigated.[13] Using a CO_2 laser beam, single pulse of 0.5 seconds, 10 watts, applied to the cover screw, implant, and gingival tissues around and above the implant head, a rise of 0.7 to 2.5°C in the temperature of the implant-bone borders was noted.

Significant heat (greater than 50°C) was generated on the lateral surface of a hydroxyapatite (HA)-coated titanium dental implant when laser energy was applied to the cover screw in a continuous mode at higher wattage levels and for longer durations. When the CO_2 laser was used for second-stage implant surgery in a pulse mode with a shorter exposure time (less than 15 seconds) and lower wattage (8 watts or less), the heat generated on the implant surfaces was less than the standard protocol.[14] The CO_2 laser produced minimal temperature changes in HA-coated and commercially pure titanium implants when used at 2 and 4 watts in continuous mode and at 6 watts in a pulse mode.[15]

The purpose of this study was to collect data related to the thermal changes that occur after the CO_2 laser beam contacts pure titanium, titanium alloy, titanium plasma spray-coated, and titanium HA-coated root-form implants placed in vitro in the mandible of a pig and in vivo in the mandibles of two dogs.

Materials and Methods

In Vitro Study. Six implants were placed in the mandible of an adult pig that had been sacrificed that morning. Implantation was performed by the conventional method using Spectra System implants (Core-Vent, Screw Vent, Bio-Vent) (Dentsply, Encino, CA) and the IMZ implant system (Friatec AG, Mannheim, Germany). The types of implants placed were: *(1)* Core-Vent, titanium-aluminum-vanadium (Ti-6Al-4V), 3.5-mm diameter, 13-mm length; *(2)* IMZ, pure titanium with a titanium plasma-spray surface, 4-mm diameter, 15-mm length; *(3)* Core-Vent, Ti-6Al-4V, 4.5-mm diameter, 10-mm length; *(4)* Screw Vent, pure titanium, 3.75-mm diameter, 13-mm length; *(5)* Bio-Vent, titanium HA-coated, 3.5-mm diameter, 10-mm length; *(6)* Screw Vent, Ti-6Al-4V, 3.75-mm diameter, 10-mm length.

Two bur holes were drilled in the bone opposite each implant (Fig 1) for contact with two thermocoupler tips. One hole was drilled in the buccal bone, third coronal part of the implant, and the other was drilled in the buccal bone, third apical part of the implant. Two copper-constant thermocouplers (Omega Engineering, Stamford, CT), 0.25 mm in diameter, were constructed and attached with bone wax directly to the implant surface (Fig 2). The thermocouplers were connected directly to a computer. Readings were collected by an analog to digital data logger type DAF-8 (Meta-Bite, Chicago, IL). Each implant was lased by a CO_2 laser handpiece (20-C Sharplan, Tel Aviv, Israel), spot size 1 mm, at a power setting of 4 and 6 watts in continuous mode, and at 5 and 8 watts in repeated pulse mode at intervals of 0.05 seconds between energy pulses. The laser beam was applied for 2, 4, and 5 seconds.

The sites of the laser beam application were the implant cover screw, the implant body, the healing screw, and the gingival tissue above and around the implant. The length of each measurement was 180 seconds, and 100 readouts were registered at each one-half second. The CO_2 laser beam was applied three times on each implant site at 15-minute intervals. Before additional lasing, the implant-bone junction was allowed to cool to its previous temperature. Data were accumulated by observing temperature changes, ie, final temperature after lasing minus

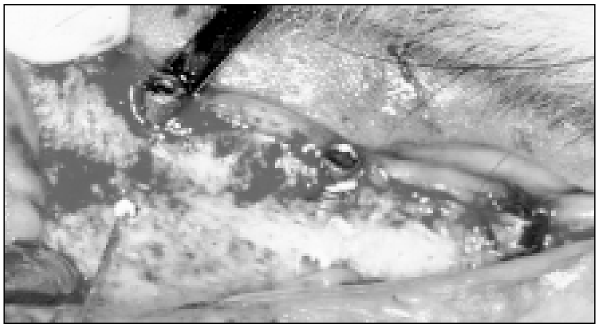

Fig 3 Exposure of three endosseous implants in a dog mandible. The thermocoupler is connected to the middle implant.

starting temperature. Readings were collected by the computer simultaneously from the two thermocouplers connected to each implant.

In Vivo Study. Two adult male foxhound dogs weighing 28 and 32 kg were used. The protocol was approved by the Institutional Animal Care Committee. The dogs received humane treatment and protection during the experiment. The dogs' mandibular right second, third, and fourth premolar teeth were extracted under general anesthesia. Four months after extractions, under general anesthesia, three endosseous implants were placed in the right mandibles using a standardized surgical protocol. In dog no. 1, the types of implants placed were: *(1)* Screw Vent Ti-6Al-4V (Spectra System), 3.75-mm diameter, 13-mm length; *(2)* Micro Vent (Spectra System), titanium-coated, 3.25-mm diameter, 13-mm length; and *(3)* Integral Calcitek System (Calcitek, Carlsbad, CA), cylinder, titanium HA-coated, 4-mm diameter, 13-mm length. In dog no. 2, the types of implants placed were *(1)* Core-Vent, Ti-6Al-4V, 4.5-mm diameter, 13-mm length; *(2)* Screw Vent, pure titanium, 3.75-mm diameter, 13-mm length; and *(3)* Integral, cylinder, titanium HA-coated, 3.25-mm diameter, 13-mm length.

Following placement of the implants, the incision was closed with 4-0 polyglactin suture. Radiographs were taken both at the time of placement and 3 months later, prior to exposure. Implant exposure with the CO_2 laser was carried out in a manner similar to the protocol used in the in vitro study (Fig 3). Two holes were drilled on the buccal side, opposite each implant, and two thermocouplers, which were attached directly to the implants, were placed. The thermocouplers were connected to a computer. The CO_2 laser handpiece was used in a 4- and 6-watt continuous mode and in a 5- and 8-watt repeated pulse at 0.05-second intervals; the laser beam was applied for 2, 4, and 5 seconds to the cover screws, the implant body, the healing screw, and the gingiva.

Results

All data were collected directly from the thermocouplers to the computer. The data in the tables are the mean measurements between the two thermocouplers (coronal and apical position) in the same position and the same parameters of lasing. In all measurements, there were no significant differences between the readings of the two thermocouplers in the same experiment.

Table 1 shows the changes in temperature that occurred when the continuous laser beam was applied to four different sites on the in vitro implants. When the continuous laser beam hit the cover screw, the healing screw, and the gingiva at different time exposures, the temperature rose from 0.75 ± 0.41°C to 7.93 ± 1.18°C. Only when the laser hit the implant body in a continuous beam at a power setting of 6 watts for 4 and 5 seconds did the temperature rise to 11.4 ± 1.55°C and 14.5 ± 1.65°C, or more than for the standard protocol.

Table 2 shows the changes in temperature that occurred when the repeated laser beam was applied at 0.05-second intervals to four different sites on the in vitro implants: the cover screw, the implant body, the healing screw, and the gingiva. In all implants, the temperature rose less than 7.62 ± 0.56°C. There were no significant differences in the temperature measurements between the various types of implants using the same laser parameters.

Tables 3 and 4 show the changes in temperature that occurred when the continuous laser beam and the repeated laser beam at 0.05-second intervals were applied to four different sites in the six in vivo implants in the mandibles of the two dogs. Only in the 6-watt continuous mode lasing for 5 seconds did the temperature rise to 12.22 ± 0.60°C; in the 6-watt continuous mode lasing for 4 seconds, the temperature rose to 9.03 ± 0.73°C. In all other experiments, the results were less than were those for the standard protocol. There were no significant differences in temperature measurements between the various types of implants when the same laser parameters were used in the in vivo experiments.

Discussion

The effect of the CO_2 laser on tissue is purely thermal. Approximately 95% of the energy is absorbed within a thin tissue layer and transformed into heat. The intra- and extracellular fluids of the target tissue

Table 1 Effect of CO_2 Laser Beam, Continuous Mode, on Implant Temperature In Vitro

Watts/ seconds	Implant no.	Temperature (°C) at each site: Cover screw	Implant body	Healing screw	Gingiva
4/2					
	1	2.4	3.9	2.0	0.3
	2	2.8	4.7	3.3	0.8
	3	2.8	5.3	2.8	0.7
	4	1.7	4.1	2.9	1.5
	5	3.4	4.5	3.3	0.5
	6	2.6	4.6	2.7	0.7
	Mean	2.62	4.52	2.83	0.75
	SD	0.56	0.49	0.48	0.41
4/4					
	1	5.9	5.3	5.2	0.7
	2	4.5	7.2	5.4	1.4
	3	5.7	6.8	5.8	1.2
	4	6.1	6.5	6.1	0.4
	5	5.1	6.9	4.4	1.3
	6	6.8	7.7	6.7	1.8
	Mean	5.68	6.73	5.60	1.13
	SD	0.80	0.81	0.79	0.50
4/5					
	1	6.4	8.4	5.2	1.4
	2	5.0	8.4	6.2	1.7
	3	5.7	6.2	7.1	0.9
	4	6.8	8.3	5.4	1.6
	5	6.1	7.0	4.5	1.0
	6	5.8	7.9	5.6	0.6
	Mean	5.97	7.70	5.67	1.20
	SD	0.62	0.91	0.89	0.43
6/2					
	1	3.7	8.0	4.4	1.4
	2	3.1	6.4	2.1	1.7
	3	4.8	8.4	3.8	1.1
	4	4.2	9.1	5.0	1.3
	5	5.3	9.3	3.7	1.2
	6	4.3	5.8	5.9	1.5
	Mean	4.23	7.83	4.15	1.37
	SD	0.78	1.43	1.29	0.22
6/4					
	1	7.2	9.1	5.2	2.5
	2	7.1	12.0	4.1	4.2
	3	6.5	11.5	7.8	1.7
	4	6.7	10.5	7.4	1.9
	5	6.4	11.8	4.4	3.0
	6	6.6	13.7	5.8	2.3
	Mean	6.75	11.43	5.78	2.60
	SD	0.33	1.54	1.53	0.91
6/5					
	1	8.4	12.4	7.8	4.4
	2	7.4	17.3	5.3	3.5
	3	10.0	14.1	9.1	6.1
	4	7.7	15.2	6.5	2.4
	5	6.5	13.8	7.4	3.6
	6	7.6	14.1	6.7	3.8
	Mean	7.93	14.48	7.13	3.97
	SD	1.18	1.65	1.29	1.23

Table 2 Effect of CO_2 Laser Beam, 0.05-Second Interval Repeated Pulse, on Implant Temperature In Vitro

Watts/ seconds	Implant no.	Temperature (°C) at each site: Cover screw	Implant body	Healing screw	Gingiva
5/2					
	1	1.3	3.1	2.6	1.1
	2	2.8	2.1	1.1	0.1
	3	1.6	2.4	1.4	0.4
	4	2.4	2.8	1.7	0.2
	5	1.1	1.9	1.9	0.5
	6	1.6	2.9	1.2	0.8
	Mean	1.80	2.53	1.65	0.52
	SD	0.66	0.48	0.55	0.38
5/4					
	1	2.4	4.3	1.4	1.4
	2	4.1	4.6	1.9	1.1
	3	2.4	4.4	2.4	0.7
	4	2.5	5.1	2.9	1.0
	5	1.4	5.5	2.2	0.6
	6	1.8	4.0	2.3	0.3
	Mean	2.43	4.65	2.18	0.85
	SD	0.92	0.55	0.50	0.39
5/5					
	1	3.1	5.4	3.9	0.9
	2	3.3	6.2	4.2	1.4
	3	3.9	6.8	3.0	1.1
	4	4.7	4.7	2.9	1.8
	5	4.0	5.0	3.9	0.4
	6	3.7	5.0	4.2	0.6
	Mean	3.78	5.52	3.68	1.03
	SD	0.57	0.82	0.58	0.52
8/2					
	1	3.1	4.4	2.4	0.4
	2	3.7	4.4	2.9	1.6
	3	3.3	4.2	3.3	1.9
	4	2.1	3.9	3.9	0.6
	5	2.4	3.3	2.4	1.0
	6	3.2	3.7	2.6	0.9
	Mean	2.97	3.98	2.92	1.07
	SD	0.60	0.44	0.59	0.58
8/4					
	1	5.2	4.9	2.9	1.9
	2	4.0	7.2	3.4	2.9
	3	3.6	6.4	3.6	2.9
	4	3.8	6.3	3.1	1.7
	5	4.4	6.0	3.3	2.0
	6	4.6	5.3	3.3	1.7
	Mean	4.27	6.02	3.27	2.18
	SD	0.59	0.82	0.24	0.57
8/5					
	1	5.8	8.4	4.4	2.9
	2	4.8	7.1	4.9	5.1
	3	4.7	7.2	5.1	3.3
	4	4.4	7.1	5.1	3.8
	5	5.2	8.0	5.2	3.3
	6	5.4	7.9	5.4	3.3
	Mean	5.05	7.62	5.02	3.62
	SD	0.51	0.56	0.34	0.78

Table 3 Effect of CO_2 Laser Beam, Continuous Mode, on Implant Temperature In Vivo

		Temperature (°C) at each site			
Watts/ seconds	Implant no.	Cover screw	Implant body	Healing screw	Gingiva
4/2					
	1	2.1	3.8	1.9	0.5
	2	2.7	3.2	2.2	1.0
	3	1.7	4.0	2.8	0.9
	4	1.9	3.0	3.0	0.4
	5	1.8	3.4	2.1	0.2
	6	2.2	3.7	2.3	0.3
	Mean	2.07	3.52	2.38	0.55
	SD	0.36	0.38	0.43	0.33
4/4					
	1	4.4	5.3	4.1	0.9
	2	4.7	5.7	4.8	1.0
	3	4.1	5.1	5.0	1.4
	4	5.0	5.0	5.3	0.5
	5	3.9	4.6	4.4	0.9
	6	4.2	6.1	4.5	1.1
	Mean	4.38	5.30	4.68	0.97
	SD	0.41	0.53	0.44	0.29
4/5					
	1	7.0	7.7	4.5	1.5
	2	5.2	6.3	6.0	1.1
	3	5.8	7.7	5.1	1.0
	4	5.8	6.1	5.6	1.3
	5	6.3	6.7	4.8	1.2
	6	6.1	6.5	5.2	1.3
	Mean	6.03	6.83	5.20	1.23
	SD	0.60	0.70	0.54	0.18
6/2					
	1	3.6	7.5	3.9	1.3
	2	4.2	8.2	3.5	0.9
	3	3.1	7.8	4.1	1.7
	4	4.0	7.2	3.4	1.7
	5	3.3	7.7	3.7	1.1
	6	3.4	7.6	3.7	1.0
	Mean	3.60	7.67	3.72	1.28
	SD	0.42	0.33	0.26	0.35
6/4					
	1	5.9	10.3	4.8	1.8
	2	5.9	8.7	5.9	1.9
	3	4.8	8.9	5.8	2.7
	4	5.5	9.4	5.3	2.4
	5	5.6	8.7	5.8	2.6
	6	5.7	8.2	5.9	2.5
	Mean	5.57	9.03	5.58	2.32
	SD	0.41	0.73	0.44	0.38
6/5					
	1	8.2	13.1	7.1	2.3
	2	8.7	11.4	6.4	2.7
	3	7.7	11.8	6.6	3.9
	4	7.9	12.1	6.9	4.4
	5	7.9	12.3	7.0	3.9
	6	8.3	12.6	6.8	4.0
	Mean	8.12	12.22	6.80	3.53
	SD	0.36	0.60	0.26	0.83

Table 4 Effect of CO_2 Laser Beam, 0.05-Second Interval Repeated Pulse, on Implant Temperature In Vivo

		Temperature (°C) at each site			
Watts/ seconds	Implant no.	Cover screw	Implant body	Healing screw	Gingiva
5/2					
	1	1.4	1.9	1.3	0.3
	2	1.7	3.0	1.6	0.9
	3	1.1	2.8	1.0	1.0
	4	1.6	2.4	1.2	0.4
	5	1.4	2.6	0.9	0.4
	6	1.5	2.3	1.9	0.5
	Mean	1.45	2.50	1.32	0.58
	SD	0.21	0.39	0.38	0.29
5/4					
	1	2.7	4.2	1.9	0.9
	2	2.0	4.7	2.8	1.3
	3	2.0	4.4	2.3	0.6
	4	3.0	4.7	2.7	0.9
	5	2.2	4.5	2.7	0.6
	6	2.2	4.7	2.4	0.7
	Mean	2.35	4.53	2.47	0.83
	SD	0.41	0.21	0.34	0.27
5/5					
	1	4.0	6.0	4.0	1.4
	2	3.0	5.4	3.0	1.1
	3	4.1	7.0	3.5	0.9
	4	3.0	6.8	3.5	0.9
	5	3.1	6.7	3.4	1.0
	6	3.1	6.2	3.6	1.0
	Mean	3.38	6.35	3.50	1.05
	SD	0.52	0.60	0.32	0.19
8/2					
	1	3.0	4.4	2.1	0.8
	2	3.4	3.4	2.8	1.3
	3	2.6	3.8	2.5	0.9
	4	3.1	4.2	2.4	1.1
	5	3.0	4.2	2.6	0.9
	6	2.5	4.1	2.5	0.7
	Mean	2.93	4.02	2.48	0.95
	SD	0.33	0.36	0.23	0.22
8/4					
	1	5.3	6.0	2.9	1.7
	2	3.3	7.0	3.6	2.4
	3	3.8	5.4	2.7	1.6
	4	3.9	5.7	2.8	1.4
	5	4.0	5.9	3.0	2.3
	6	4.0	6.2	3.3	1.7
	Mean	4.05	6.03	3.05	1.85
	SD	0.67	0.55	0.34	0.40
8/5					
	1	5.5	6.9	4.9	3.3
	2	6.1	8.5	4.4	2.3
	3	4.7	8.3	4.6	2.9
	4	5.0	7.4	4.7	2.5
	5	5.0	7.5	4.9	2.7
	6	5.3	7.6	4.9	2.8
	Mean	5.27	7.70	4.73	2.75
	SD	0.49	0.60	0.21	0.34

are rapidly evaporated, and this is followed by cell destruction. Since living tissue is a poor heat conductor, thermal damage to adjacent tissue is restricted to a very narrow zone. Blood vessels less than 0.5 mm to 1.0 mm in diameter are sealed. The penetration depth can readily be controlled, thus allowing precise surgery. This, together with a dry, almost bloodless operative field, makes the CO_2 laser an ideal tool for tissue ablation.

In peri-implant surgery, the gingivae and mucosae around and above the implant are either incised or excised. The proximity of the implant prevents the possibility of an accidental hit of the beam to the implant. Thus, the question arises as to the amount of heat transferred along the implant and, accordingly, damage to the surrounding bone. Since the implant is made of metal, it reflects most of the beam. The CO_2 laser beam hits the implant coincidentally and for only a very short time; thus, the bone surrounding the implant would be minimally affected.

The CO_2 laser appears to be safe to use around titanium plasma spray-coated and HA-coated cylinders and screw implants at power levels of less than 4 watts in a continuous mode and at less than 8 watts in a repeated pulse of 0.05 seconds. These power densities (watts/cm^2) are clinically useful for most peri-implant procedures.

Conclusion

The laser, which represents one of the most revolutionary mechanisms for selective application of thermal energy to tissues, enables peri-implant surgery to be performed with maximum safety against thermal destruction. Together with all the advantages of laser surgery, it appears that, from the data gathered by this study, this surgical technique is safe.

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