Temperature Effect on Hard Dental Tissues and Amalgam Filling Induced by CO_2 Laser Irradiotion

Toplinski učinak CO_2 lasera na tvrda zubna tkiva i amalgamske ispune

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Summary

Effects of temperature changes on extracted human teeth, amalgam surface and during ablation of cervical caries produced by CO_2 laser irradiation were examined. On extracted molars, the bottom of occlusal class I preparations were with output power of 3 W for 5 and 10 s. Temperature elevations recorded at cross-section surface of the holes of 3 mm in diameter, previously prepared on buccal surface toward pulp chamber, were between +7.3^{0}C and temperatures which were beyond the calibration range (>50^{0}C) of the thermovision device. On non-polished amalgam class II restorations, laser power of 1 W for 3 s, measured at impact points, produced immediately after lasing a maximal rise in temperature higher than 50^{0}C (>+15^{0}C), beyond the camera calibration range. The same temperature rise was recorded after ablation of cervical caries with laser power of 2 W for 5 s.

Key words: *CO_2 laser, Dental hard tissue, Dental caries, Amalgam, Temperature changes*

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Introduction

Numerous dental studies have used different types of lasers in order to obtain caries ablation. According to the results of this study, CO_2 laser as well as Nd: YAG And excimer lasers are capable of ablating and vaporizing dentin, cementum and organic debris including microorganisms, without inflicting appreciable damage to the adjacent dental or periodontal tissues (1-4).

To the CO_2 laser operated at a wavelength (10.6 m) that is highly absorbed by dentine and enamel. This very important due to the fact that only the absorbed energy is converted into heat which produces burn, melt or vaporizes the matrix (5). Nelson et al (6) used CO_2 laser measured, at the enamel surface during lasing, by infrared pyrometry temperatures of 810-105^{0}C and even considered these to be an underestimate. Jeffrey et al. (7) report that at depths of overlaying dentin of up to 3 mm. laser-induced thermal damage to the dental pulp is a definite possibility. However, the temperatures recorded at the enamel and dentin surface (target areas) are quite different from these recorded inside the dental pulp (8,9) when whole tooth (instead of the particles of dentin or enamel) is irradiated by laser. In their in vivo study on class V cavity made on 40 premolars, lased by CO_2 laser and extracted after 15, 30, 50 and 80 days, Franquin and Salamon found no pulpal inflammation or irreversible degeneration of the pulp tissue (10). on the contrary, they found that CO_2 laser may stimulate the production of reactionary dentin layer. Gertich et al. (11) have also reported that precise removal of dentin with a very short pulsed mini-TEA-CO_2 laser is possible without causing thermal damage to this tissue. Furthermore, Bonin et al. (12) report that (in an animal model) it is possible to obtain sealing of dentinal tubules by CO_2 laser irradiation without affecting the underlying pulp. Melcer (4) reports that simple tooth decay can be treated by static exposure (4 and 6W, focused pulse beam, 0.2 s) or by dynamic exposure of approximately 1 s exposure time for (CW) at a speed of about 3 cm per second. As the teeth treated by the author were immediately functional, the treatments involved no pain and, after the treatment the pulp was capable to recover its physiological balance, the assumption is that it is possible to avoid thermal damage to the pulp. In contrast based on a study on 51 human teeth irradiated before extraction, de Raad and Paschoudy (13) report that the underlying pulp (in projection of impact point) showed disintegration of odontoblastic layer and edema.

Near-infrared laser radiation of the 1064 nm wavelength from Nd: YAG lasers is strongly absorbed by many metals. In contrast , the CO_2 laser energy is not absorbed to any significant extent by the metallic surface. The same is true for amalgam restorations, which are not ablated by CO_2 laser irradiation (14).

The purposes of this study were three-fold: first, to measure temperature elevation on the buccal enamel and cement surface as well as at the cross section of the hole prepared toward the pulp chamber, during and after lasing of the bottom of occlusal class I cavities on extracted human molars; second, to measure temperature elevation during and after partial ablation of cervical caries on the canines; and third, to measure temperature changes of non-polished amalgam class II restorations during and after irradiation by CO_2 laser.

Materials and methods

Laser device

A Sharplan 1060 CO_2 laser (Sharplan, Tel-Aviv, Israel) with He-Ne laser guiding beam and coupled with a surgical microscope was used in the study. Continuous wave (CW), 1 mm spot size with selected powers of 1, 2, and 3 W, and irradiation times of 1, 2, 3, 5 and 10 seconds were used. During lasing, all specimens were placed on a Styrofoam holder and positioned at a 20-cm distance from the tip of the laser. The laser beam was directed at the right angle to the target surface for maximum energy absorption.

Thermovision system

The rise in temperature and heat flow over the monitored areas were recorded in real time on VTR by means of a Topscan 808 thermovision camera (Iskra Elektrooptika, Ljubljana, Slovenia). The camera sensitivity is 0.15^{0}C with time resolution of 10 pictures per second. A rise in temperature of 10^{0}C was considered critical overheating, thus the camera was calibrated to measure temperature changes between 20 and 50^{0}C. While measuring the temperature, the measurement points were indicated on the "frozen) screen using a computer cursor. The recorded values were immediately processed using a computerized thermal image processing system TIPS 808, developed at VAMS (Visual Analysis and Measurement Systems, Zagreb, Croatia) . To avoid the reflection of infrared irradiation from the laser and specimen, which could have affected the temperature measurements, the analyzing process was triggered immediately after the laser action.

Teeth samples

In this study, a) 40 healthy lower third human molars, b) 15 molars with class II (mesio-occlusal- distal) amalgam restorations, and c) 10 canines with cervical caries extracted for periodontal reason, were used. The teeth were preserved in 10% formalin for one month and then cleansed mechanically and ultrasonically. After cleansing, the teeth were washed with saline and stored at 37^{0}C until the experiment.

Table 1. *Experimantal groups and laser parmeters used*
Tablica 1. *Eksperimentalne skupine i parametri obasjavanja laserom.*

	Group	Beam spot size mm	Laser mode	Laser power W	Irradiation time (s)	N
Healthy molars	A	1	CW	2	5	10
class I cavities	B	1	CW	2	10	10
	C	1	CW	3	5	10
	D	1	CW	3	10	10
	E	1	CW	1	1	5
Amalgam fillings	F	1	CW	1	2	5
	G	1	CW	1	3	5
Canines	H	1	CW	2	5	5
Cervical caries	I	1	CW	2	10	5

a) Prior to irradiation, 40 healthy molars were randomly divided in to four groups of 10 samples each (A-D). On the occlusal surface of the samples, the class I preparation was made by water cooling cylindrical high-speed diamond drills. The cavity bottom made just beyond the dentine-enamel junction. On the buccal surfaces, approximately 2 mm above the bifurcation, a hole of 3 mm in diameter was drilled through the enamel and dentin to expose pulp chamber. In experimental groups A-D, the cavity bottom was lased with the parameters present ed in Table 1. Figure 1 presents the designated measurement points at the buccal surface of lased molars.

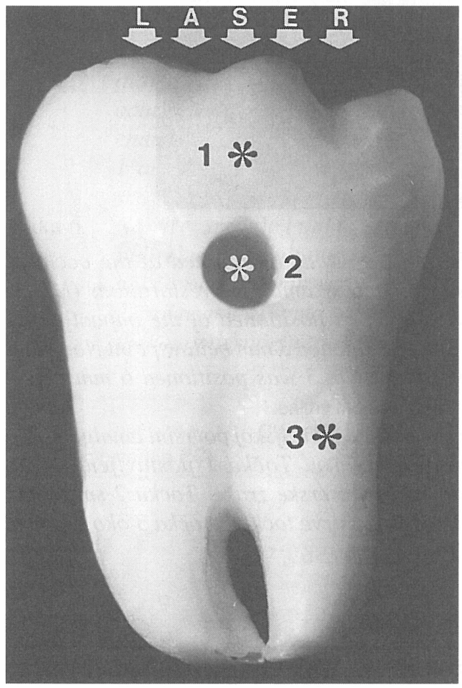

Figure 1. *Measurement points designated by computer cursor at the buccal enamel (No. 1), cross-section surface of the hole drilled through enamel and dentin toward pulp chamber (No. 2) and at the surface of the distal root (No. 3) of the sound molar.*
Slika 1. *Mjerne točke odabrane računalom na bukalnoj caklini molara (točka 1), na presjeku bušotine kroz caklinu i dentin do pulpne komorice (točka 2) i na površini distalnog korjena (točka 3).*

b) The molars with non-polished amalgam restorations were randomly divided into three groups of 5 samples each (E,F,G). The teeth were mounted on a styrofoam holder, so that each one was placed on distal-approximal surface, thus

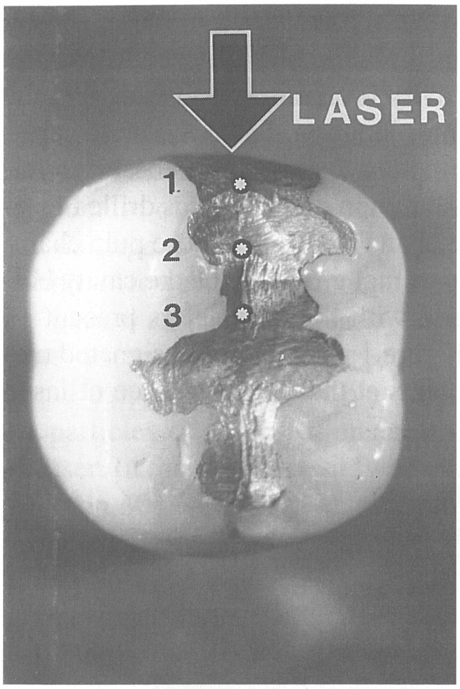

Figure 2. *Measurement points designated at the occlusal surface the molar amalgam restorations (MOD) Point No. 1 was positioned at the impact point, No. 2 was positioned 3 mm bellow point No. 1 and finally, point No. 3 was positioned 6 mm below point No. 1.*

Slika 2. *Mjerne točke na okluzijskoj površini amalgamskog ispuna na molaru. Točka 1 postavljena je na mjestu udara laserske zrake. Točka 2 smještena je tri mm ispod prve točke, a točka 3 oko šest mm ispod prve točke.*

the occlusal surface was positioned in front of the thermovision camera. The mesial-approximal amalgam marginal ridge of specimens was lased with the parameters shown in Table 1. The measurement points are present ed in Figure 2.

c) The canines were divided in to two groups of 5 samples each (H,I). The teeth were mounted on a styrofoam holder with their long axis in the horizontal position. The buccal surface was positioned in front of the thermovision camera, and laser beam was directed perpendicular by to the long axis. During caries ablation the teeth were fixed, so that one side was irradiated. The irradiation parameters are present ed in Table 1 and measurement points in Figure 3.

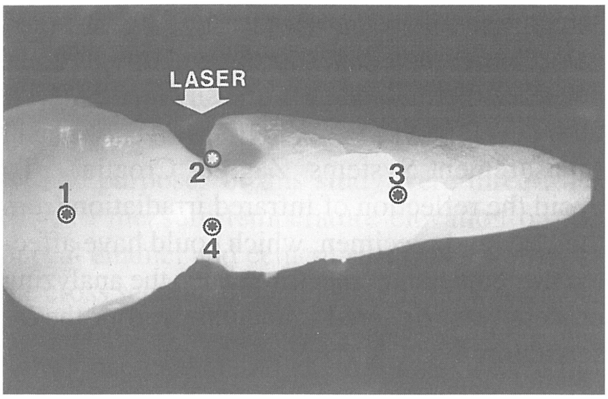

Figure 3. *Measurement points designated at the buccal surface of the canine during and after laser ablation of cervical caries. Point No. 2 was positioned at the buccal enamel surface, point No. 1 was positioned at the impact area, point No. 3 at the surface in the middle third of the root, and finally, point No. 4 at the area positioned approximately 3 mm oposite to the No. 1.*

Slika 3. *Mjerne točke na bukalnoj stijenci očnjaka tijekom i nakon fotoablacije cerviksnog karijesa laserom. Točka 2. smještena je na bukalnoj caklini, točka 1 na mjestu djelovanja laserske zrake, a točka 3. na površini srednje trećine korijena. Točka 4. smještena je otprilike tri mm nasuprot točke 1.*

Results

Temperature changes in healthy molars

Temperature changes dependent on the time and laser parameters as well as starting temperature recorded in healthy molars, are shown in Figures 4-7. Only with laser power of 3 W and 10 s irradiation time, temperature values were only measurable for a short time (1.8 s) at the cross section surface of the buccal hole after the laser action had been stopped. During this period, temperature rises of +10.6-11.2^{0}C were recorded. Thereafter, until the end of the measurement period, temperatures were beyond the calibration range of the thermovision camera (>50^{0}C). Heat distribution over the buccal and cross section surface of the sample immediately after lasing in shown in Figure 8.

Temperature changes in amalgam restorations

CO_2 laser power of 1W/1s produced a hardly noticeable or no measurable amount of heat

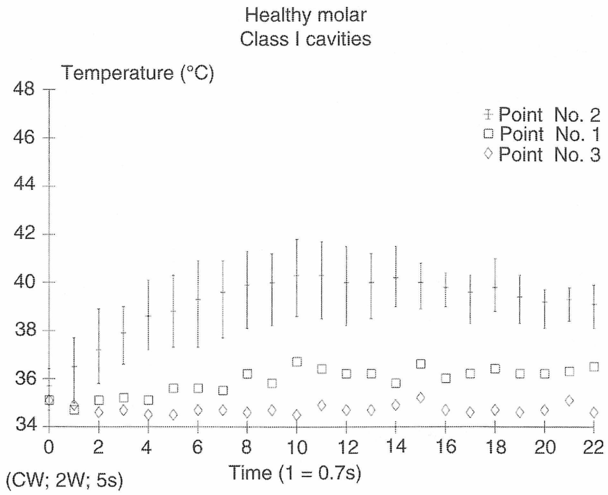

Figure 4. *The highest, mean and the lowest temperature recorded indirectly, after lasing the bottom of Class I oclusal preparation with 2W/5s, inside the pulp chamber of sound molar (No. 2). For points No. 1 and 3 only the highest measured values are shown.*

Slika 4. *Najviše, srednje i najniže vrijednosti temperatura izmjerenih indirektno, u pulpnoj komorici molara (No. 2) nakon obasjavanja snagom od 2W/5s. Za točke 1. i 3. prikazane su samo najviše vrijednosti izmjerene tijekom mjernog perioda.*

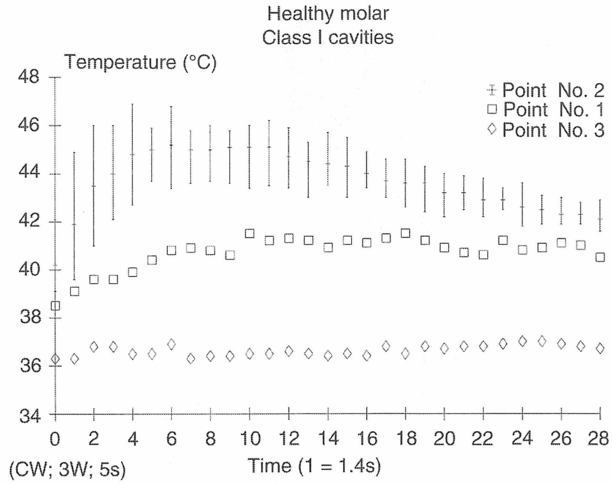

Figure 6. *The highest, mean and the lowest values recorded indirectly, after lasing the bottom of Class I oclusal preparation with 3W/5s, inside the pulp chamber of sound molar (No. 2). For points No. 1 and 3 only the highest measured values are shown.*

Slika 6. *Najviše, srednje i najniže temperature izmjerene, indirektno, u pulpnoj komorici molara (No. 2) nakon obasjavanja snagom 3W/5s. Za točke 1. i 3. prikazane su samo najviše vrijednosti izmjerene tijekom mjernog perioda.*

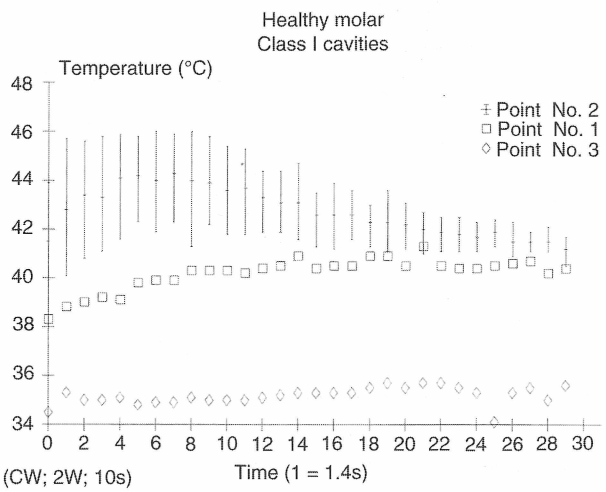

Figure 5. *The highest, mean and the lowest values recorded indirectly, after lasing the bottom of Class I oclusal preparation with 2W/10s, inside the pulp chamber of sound molar (No. 2). For points No. 1 and 3 only the highest measured values are shown.*

Slika 5. *Najviše, srednje i najniže vrijednosti izmjerene, indirektno, u pulpnoj komorici molara (No. 2) nakon obasjavanja snagom 2W/10s. Za točke 1. i 3. prikazane su samo najviše vrijednosti izmjerene tijekom mjernog perioda.*

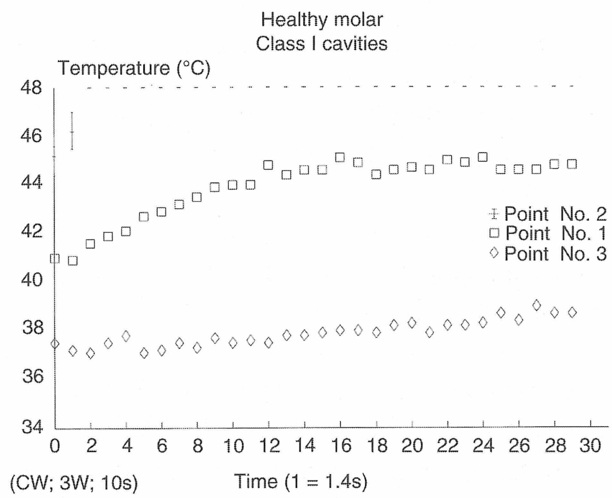

Figure 7. *The highest, mean and the lowest values recorded indirectly, after lasing the bottom of Class I oclusal preparation with 3W/10s, inside the pulp chamber of sound molar (No. 2). For measurement points No. 1 and 3 only the highest measured values are shown.*

Slika 7. *Najviše, srednje i najniže vrijednosti izmjerene, indirektno, u pulpnoj komorici molara (No. 2) nakon obasjavanja snagom 3W/10s. Za točke 1. i 3. prikazane su samo najviše vrijednosti izmjerene tijekom mjernog perioda.*

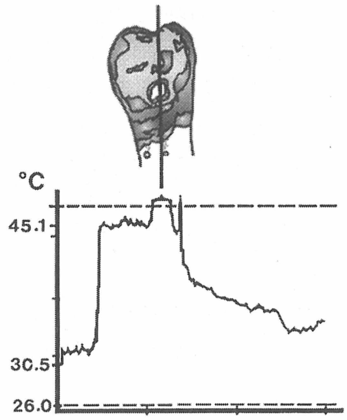

Figure 8. *Temperature values recorded immediately after laser action was stopped. The line over the buccal surface present measurement area.*

Slika 8. *Temperature izmjerene neposredno nakon obasjavanja. Linija preko bukalne plohe označava područje mjerenja temperature.*

(group E). The rise in temperature of +5.9°C (measurable point No. 1) was recorded after lasing with 1W/2s. However, at the end of the measurement period, the temperatures were lower than the starting, temperature before lasing.

Laser power of 1W/3 s (group G) produced a rise in temperature over 50°C, however, the temperature abruptly decreased and only 0.5 s after lasing the peak temperature was a 40.5°C (+5.7°C).

The time-and parameters dependent temperature changes as well as the starting temperature are shown in Figures 9 and 10.

Temperature changes after cervical caries ablation

In the center of the lased area (measurement point No. 2), the peak temperature after lasing was beyond the camera calibration rang (>50°C) during the first 2.1 s of the measurement period (Fig. 11). The first measurable temperature was 41.2°C (+7.7°C), and at the end of the measurable period the temperature was about 38.0°C (+4.5°C). Heat distribution and temperature changes over the buccal surface of the canine are shown in Figure 12.

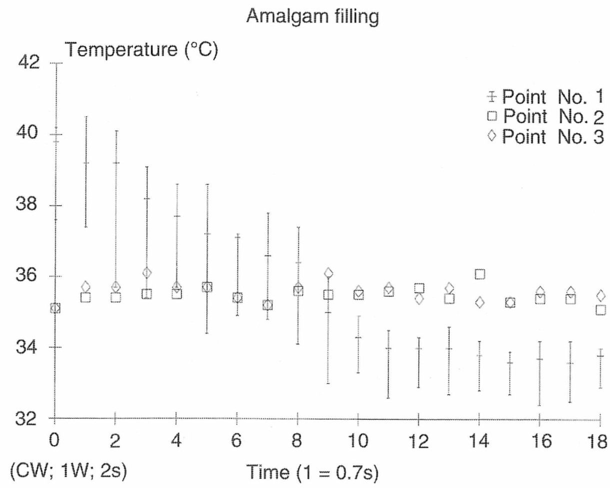

Figure 9. *Temperature changes over the occlusal amalgam surface following irradiation by CO_2 laser power of 1W/2s. The highest, mean and lowest values are shown only for calues measured at the impact point (No. 1). For the other two areas (No. 2 and 3), the highest values are shown.*

Slika 9. *Promjene temperature izmjerene na okluzijskoj plohi amalgamskog ispuna nakon obasjavanja s 1W/2s. Najviše, srednje i najniže vrijednosti dane su samo za obasjavano područje (točka 1), dok su za ostala mjerna područja (točke 2. i 3.) prikazane najviše izmjerene vrijednosti.*

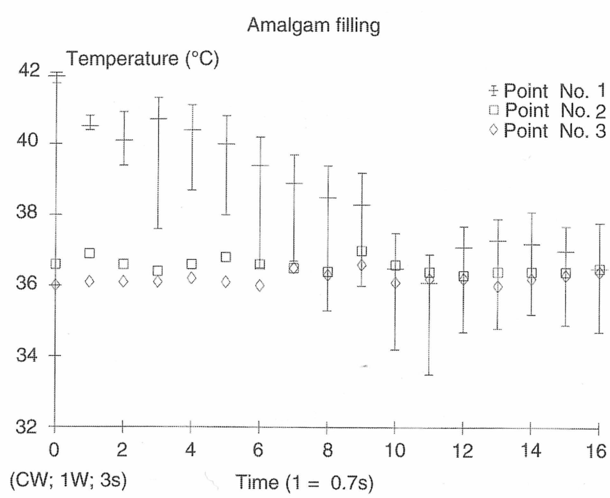

Figure 10. *Temperature changes over the occlusal amalgam surface following irradiation by CO_2 laser power of 1W/3s. The highest, mean and the lowest values are shown only for the impact point (No. 1). For the other two areas (No. 2 and 3), the highest values are shown.*

Slika 10. *Promjene temperature izmjerene na okluzijskoj plohi amalgamskog ispuna nakon obasjavanja s 1W/23s. Najviše, srednje i najniže vrijednosti dane su samo za obasjavano područje (točka 1), dok su za ostala mjerna područja (točke 2. i 3.) prikazane najviše izmjerene vrijednosti.*

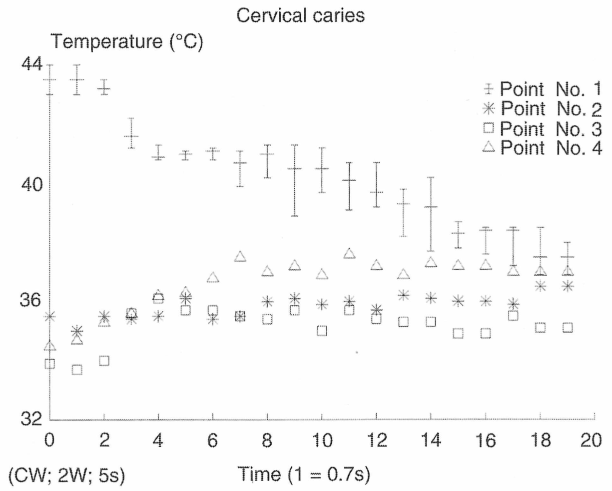

Figure 11. *Temperature changes recorded after unilateral photoablation of cervical caries using a CO_2 laser beam CW/2W/5s. The highest, mean and the lowest values recorded at the impact area (No. 2) and only the highest values measured at the other three areas (No. 1, 3 and 4) are shown.*

Slika 10. *Temperaturne promjene izmjerene nakon jednostrane fotoablacije cerviksnog karijesa CO_2 laserom snage 2W/CW/5s. Najviše, srednje i najniže vrijednosti prikazane su samo za obasjavano područje (točka 2) dok su za preostala tri (točke 1, 3 i 4) prikazane samo najviše izmjerene vrijednosti.*

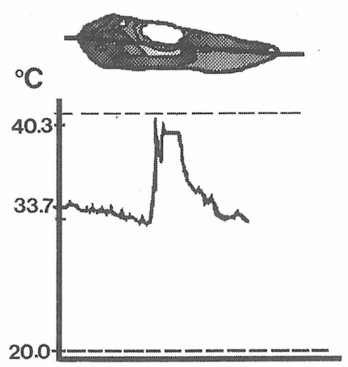

Figure 12. *Temperature values recorded immediately after laser action was stopped. The line over the buccal surface of the cannine, present measurement area.*

Slika 12. *Temperature izmjerene neposredno nakon obasjavanja. Linija preko bukalne plohe očnjaka označava područje mjerenja temperature.*

Discussion

The results obtained showed that the CO_2 laser irradiation can, in certain conditions, produce thermal damage to the pulp tissue. A temperature elevation of not more than 5.5^{0}C was sufficient to cause damage to the dental pulp in several small teeth (15). It is interesting that rise in temperature at the dentin surface, induced by CO_2 laser, is lower compared to the enamel one, because dentin contains more organic tissue and water. Vaporizing of water during lasing partially limits overheating (16). However, in this study, the rises in temperature recorded at the enamel and cementum surface were lower than the temperature inside the vacant pulp chamber (the temperature measured at the cross-section of the buccal hole. It should be remembered that the numerical thermal conductivity of dentin (average 5.71-5.84x10^{-3} J/s/cm^2/^{0}C/cm) is independent of dentin thickness, but the effectiveness of dentin as an insulator is directly proportional to the thickness of the dentin wall. Beside, an in vivo condition, i.e. the temperature inside the chamber, should be lower due to the effect of pulpal blood vessels.

Jeffrey et al. (7) have reported that, after CO_2 laser action, more than a half of dentin specimens of 2 and 3 mm thickness, approximated or exceeded the temperature at which irreversible pulp damage is believed to occur. The results of this study are opposite to this report. However, in the present study, the whole teeth instead dentin slides were used, thus a greater mass of enamel and dentin was capable to absorb and dissipate much more laser energy.

Based on Melcer parameters (17), Launay et al. (14) found in vitro the rise in temperature from 0^{0}C to +2^{0}C and from +1^{0}C to 07^{0}C following lasing with CO_2 laser with energy density of 800 J/cm^2. These results correspond to our findings of maximal temperature elevation induced by CO_2 laser irradiation with 2W/5s, observed at the cross-section surface of the molar pulp chamber opening (+7^{0}C).

Miserendino et al. (8) have reported that maximal temperature rise was achieved within 30-60 s following lasing with CW for more than 0.5 s. They also observed that laser fall within below 10 J/cm^2 produced temperature elevation below 5.5^{0}C, which may fall within the range of pulpal tolerance. In the present study, the peak temperature inside the vacant pulp chamber was recorded within the first 20 s after lasing. Furthermore, temperatures capable of producing irreparable pulp damage, and sufficient time duration of such high temperature were recorded. However, it was due to the fact that a higher energy level and prolonged irradiation time than in the previously mentioned study were used.

The result of this study are partially in agreement with those reported by Neiburger and Miserendino (18). These authors report that even powers of 24W/0.5 s with 1 mm beam diameter did not present a health threat to the molar pulp when enamel was lased. The exposures between 9 and 24 W resulted in maximal temperature rise inside the pulp chamber od 0.5 to 3.5^{0}C.

Technically, ablation of cervical lcaries could be done with CO_2 laser irradiation of 2W/5 s, but on the impact area, these parameters produced high temperatures. The temperature reached peak values during lasing. The cooling process was rapid during the first second of post-irradiation time, but thereafter, the decrease in temperature was moderate. This means that lower energy or considerably prolonged irradiation time should be used to avoid pulp tissue necrosis. Also, it should be emphasized the cervical portion and not inside the pulp space.

The CO_2 laser power of 1W/1s on the surface of non-polished amalgam filling produced a very low rise in temperature or, in some cases, did not produce any amount of temperature measurable en the thermovision system used.

Conclusions

During lasing the dentin on the bottom of class I cavity, the CO_2 laser irradiation can, in certain conditions, produce thermal damage to the pulp tissue.

Technically, ablation of cervical caries on human canines could be done, in vitro, by the CO_2 laser exposure of 2W/5s. However, on the impact surface these parameters produced very high temperature elevations.

Immediately after lasing, CO_2 laser power of 1W/3s can produce very high temperature at the impact point. however, due to the amalgam thermal conductivity, the temperature abruptly decreases.

TOPLINSKI UČINAK CO_2 LASERA NA TVRDA ZUBNA TKIVA I AMALGAMSKE ISPUNE

Sažetak

U radu je ispitivan temperaturni učinak CO_2 lasera na zubno tkivo i amalgam. Dno okluzijskog kaviteta I. razreda kod 40 trajnih zdravih molara obasjano je s 3W kroz 5 i 10 sekundi. Promjene temperature mjerene su bukalnoj caklini, površini korijena i, indirektno, u pranoj pulpnoj komorici. Nakon obasjavanja, u pulpnoj komorici temperatura je porasla za najmanje +7.5^{0}C do više od 20^{0}C. Nakon obasjavanja troplošnoga amalgamskog ispuna na molarima snagom od 1W kroz 3 s, na ciljanu mjestu temperatura je porasla za više od 15-20^{0}C. Samo 0,5 sekundi kasnije, temperatura je bila povišena za +5.7^{0}C. Isti porast tempe-

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rature izmjeren je i nakon fotoablacije cerviksnog karijesa na ekstrahiranim očnjacima, ali je hlađenje bilo znatno sporije.

Ključne riječi: *CO_2 laser, tvrda zubna tkiva, karijes, amalgam, temperaturne razlike*

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