Temperature Effect on Hard Dental Tissues and Amalgam Filling Induced by CO₂ Laser Irradiation

Toplinski učinak CO₂ lasera na tvrda zubna tkiva i amalgamske ispune

Summary

Effects of temperature changes on extracted human teeth, amalgam surface and during ablation of cervical caries produced by CO₂ 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°C and temperatures which were beyond the calibration range (>50°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°C (>+15°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: CO₂ laser, Dental hard tissue, Dental caries, Amalgam, Temperature changes

Introduction

Numerous dental studies have used different types of lasers in order to obtain caries ablation. According to the results of this study, CO₂ 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 CO₂ 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 ma-
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trix (5). Nelson et al (6) used CO\textsubscript{2} laser measured, at the enamel surface during lasing, by infrared pyrometry temperatures of 810-105°C and even considered these to be an underestimate. Jeffrey et al. (7) report that at depths of overlying 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\textsubscript{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\textsubscript{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\textsubscript{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 reactionary dentinal tubules by CO\textsubscript{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\textsubscript{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\textsubscript{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\textsubscript{2} laser.

Materials and methods

Laser device

A Sharplan 1060 CO\textsubscript{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°C with time resolution of 10 pictures per second. A rise in temperature of 10°C was considered critical overheating, thus the camera was calibrated to measure temperature changes between 20 and 50°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°C until the experiment.

<table>
<thead>
<tr>
<th>Healthy molars</th>
<th>Group</th>
<th>Beam spot size mm</th>
<th>Laser mode</th>
<th>Laser power W</th>
<th>Irradiation time (s)</th>
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<td>class I cavities</td>
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<td>Amalgam fillings</td>
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<td>Cervical caries</td>
<td>I</td>
<td>1</td>
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Table 1. Experimantal groups and laser parmeters used
Tablica 1. Eksperimentalne skupine i parametri obasjavanja laserom.

a) Prior to irradiation, 40 healthy molars were randomly divided into 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 presented 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.](image)

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
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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 lasered 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 opposite to the No. 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°C were recorded. Thereafter, until the end of the measurement period, temperatures were beyond the calibration range of the thermovision camera (>50°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

CO₂ laser power of 1W/1s produced a hardly noticeable or no measurable amount of heat
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Healthy molar  
Class I cavities

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 temperature izmjerene 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 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 temperature izmjerene, indirektno, u pulpoj komorici molara (No. 2) nakon obasjavanja snagom 2W/10s. 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 pulpoj komorici molara (No. 2) nakon obasjavanja snagom 3W/5s. 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 temperature izmjerene, indirektno, u pulpoj komorici molara (No. 2) nakon obasjavanja snagom 3W/10s. Za točke 1. i 3. prikazane su samo najviše vrijednosti izmjerene tijekom mjernog perioda.
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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 las­sing 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.
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Temperature (°C)

(CW; 2W; 5s) Time (1 = 0.7s)

Figure 11. Temperature changes recorded after unilateral photoablation of cervical caries using a CO\textsubscript{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\textsubscript{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.

Discussion

The results obtained showed that the CO\textsubscript{2} laser irradiation can, in certain conditions, produce thermal damage to the pulp tissue. A temperature elevation of not more than 5.5°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\textsubscript{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 5.71-5.84\times10^{-3}\, J/s/cm²/°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. Besides 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\textsubscript{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°C to +2°C and from +1°C to 07°C following lasing with CO\textsubscript{2} laser with energy density of 800 J/cm\textsuperscript{2}. These results correspond to our findings of maximal temperature elevation induced by CO\textsubscript{2} laser irradiation with 2W/5s, observed at the cross-section surface of the molar pulp chamber opening (+7°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\textsuperscript{2} produced temperature elevati-
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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 CO₂ 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 on the thermovision system used.

**Conclusions**

During lasing the dentin on the bottom of class I cavity, the CO₂ 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 CO₂ laser exposure of 2W/5s. However, on the impact surface these parameters produced very high temperature elevations.

Immediately after lasing, CO₂ 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.

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**TOPLINSKI UČINAK CO₂ LASERA NA TVRDA ZUBNA TKIVA I AMALGAMSKE ISPUNE**

Sažetak

U radu je ispitivan temperaturni učinak CO₂ 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 mjerenu bukalnoj caklini, površini korijena i, indirektno, u pranoj pulpnoj komorici. Nakon obasjavanja, u pulpnoj komorici temperatura je porasla za najmanje +7.5°C do više od 20°C. Nakon obasjavanja troposnošnog amalgamskog ispuna na molarima snagom od 1W kroz 3s, na ciljanu mjestu temperatura je porasla za više od 15-20°C. Samo, 0.5 sekundi kasnije, temperatura je bila povišena za +5.7°C. Isti porast temperaturi nareden je...
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Ključne riječi: $\text{CO}_2$ laser, tvrda zubna tkiva, karijes, amalgam, temperaturne razlike

References