Effects of Copper Vapor Laser Irradiation ($\lambda = 510.6$ nm) on the Enamel and Dentine of Human Teeth: An Ultra-structural Morphologic Study

WALTER NICCOLI-FILHO, D.D.S., Ph.D.,¹ LUIZ ALBERTO PLÁCIDO PENNA, D.D.S., M.S.D.,²
SIGMAR MELLO RODE, D.D.S., Ph.D.,³ and RUDIMAR RIVA, D.Ph.S., Eng.⁴

ABSTRACT

Objective: A morphological and ultra-structural study of copper vapor laser ($\lambda = 510.6$ nm) effects on enamel and dentine was performed to show the effects of this radiation. **Methods:** A total of 15 human molars were cut in half; 15 pieces were separated for irradiation on enamel and 15 for dentine. These two groups were further divided into five experimental groups, including a control group, comprised of three half-sections each, irradiated by a CVL laser with a power of 7 W, a repetition rate of 15,000 pulses/sec and exposed at 500, 600, and 800 msec and 1 sec irradiation times with a 5-sec interval between irradiations. **Results:** In an ultra-structural SEM exam, we observed that on the enamel surfaces irradiated for 1 sec there was morphological alteration that consisted of catering, flaking, and melting on the surfaces. There was no alteration for the other exposure times. On the dentine teeth irradiated for 1 sec, we observed an evident ultra-structural alteration of melted tissue and loss of morphological characteristics. In the dentine group irradiated by 800 msec, we observed ablation and a partial loss of morphological characteristics. In the dentine groups irradiated by 500 and 600 msec, no alteration was observed. **Conclusions:** The results showed that irradiation with CVL promoted morphologic changes in the enamel as well as in the dentine and demonstrated a need for future studies in order to establish a safe protocol for further use in the odontological practice.

INTRODUCTION

THE LASER has already become part of our daily reality and has many applications as a medical-odontological instrument. However, lack of knowledge and incorrect application can provide incorrect information and limit progress in the odontological community. The limitations as well as the benefits of using lasers must be researched in order to prevent misapplications from hindering progress. When lasers are used with the correct settings and indications, there are many advantages.

The ability to precisely control a high level of light energy has countless clinical-surgical applications that are dependent upon the specific wavelength of the selected laser. The use of

surgical lasers on soft tissue has been extensively studied in the last decade, and, more recently, its application on mineralized tissues has aroused scientific curiosity.^{1–6}

Niccoli-Filho and Okamoto,⁷ using an Nd:YAG continuous laser on the tooth extraction wounds of a rat, have demonstrated that the heat generated in the alveolus not only delayed the repair chronology but also affected the quality of the repair process.

Some authors state that high-power lasers have the potential to sterilize the dentine surface. However, because there is a risk of tissue damage, the amount of heat generated is a subject of great interest for researchers in the field of dentistry.^{8–15} Research shows degenerative changes and dental pulp necrosis after the accidental or deliberate irradiation of teeth during sur-

¹Academic Group Studies and Research with Lasers in Dentistry, Sao Paulo State University School of Dentistry, Sao Jose dos Campos, Sao Paulo, Brazil.

²Maxillofacial Prosthesis, Sao Paulo State University School of Dentistry, Sao Jose dos Campos, Sao Paulo, Brazil.

³Odontological Materials and Prosthesis, Sao Paulo State University School of Dentistry, Sao Jose dos Campos, Sao Paulo, Brazil.

⁴Department of Physics, Advanced Studies Institute, IEAv, Lasers Division, Sao Jose dos Campos, Sao Paulo, Brazil.

gical procedures. This suggests a potential risk when high-energy lasers are used on the mouth.^{9,11,14,16–20} Differences in results can be attributed to variations in methodology, differences in test animals used, the type of tissue, the physical characteristics of each type of laser and their wavelength and their different powers, exposure times and energies. The potential to thermally damage the pulp and the buccal tissue is a risk that is dependent upon the exposure time and the power level. Therefore, safety parameters should be established when lasers are used on buccal tissue.

Despite the fact that the use of the copper vapor laser (CVL) is a very recent development (from the 1990s), it has aroused interest because it generates high-power coherent radiation in the visible region of the spectrum and has a high efficiency electric power conversion to radiation, as compared to other lasers operating in the same spectrum band. With short-duration pulses (10–50 nm), this laser has found several applications in the medical field.

In medical applications, the CVL laser has been selected as a replacement for the argon laser in vascular lesions because it converts high electric power efficiency to luminosity.^{21–25}

This study investigates potential ultra-structural morphologic alterations in the enamel and dentine of human teeth after direct exposure to CVL laser radiation with different exposure times.

MATERIALS AND METHODS

Fifteen human molars, free of restorations and/or caries (stored in a solution of NaCl 9%), were selected to be exposed to CVL laser radiation.

After the orientation furrows in the sense mesial had been cleaved by a rotatory cylindrical cutting instrument number 1095 (K.G. Sorensen), the teeth were separated with a chisel and surgical hammer into two half-sections in order to obtain a dentine surface with no interference from a smear layer. They were then randomly divided into five groups with three half-sections of teeth to each group; for irradiation of the enamel (1E, 2E, 3E, 4E and 5E), for irradiation of the dentine (1D, 2D, 3D, 4D and 5D) with group 5E and 5D as control.

The teeth were horizontally fastened with utility wax to a metallic base actuator, by means of a pantographic system, allowing for vertical adjustments of focus on the defined irradiated area.

CVL laser radiation with a wavelength of 510.6 nm was applied to the vestibule face of the teeth and to the dentine surfaces exposed by the fracture through an optic fiber with a diameter of 0.4 mm, focus of 0.8 mm, power of 7 W, repetition rate of 15,000 pulses/sec, total power density of 5570 W/cm², fluency at 2789 J/cm², and with a 5-sec interval between irradiations. This application was repeated on the other groups with exposure times of 500 msec (3.5 J), 600 msec (4.2 J), 800 msec (5.6 J), and 1 sec (7.0 J) (Table 1).

The teeth, stored in a sterile, covered container, were cleaned with distilled water and an ultra-sound device, dried in a hot air sterilizer, and mounted with metallic supports of aluminum, which was then covered with gold by conventional techniques. The teeth were then analyzed and photographed with an scanning electron microscope (SEM), with a magnification that varied from 100 to 3000×, for comparative morphologic study.

TABLE 1. IRRADIATION OF TEETH, THE RESPECTIVE EXPOSURE TIME, AND THE IRRADIANCE

Group	Exposure time	Irradiance (Joules)
1E, 1D	500 msec	3.5
2E, 2D	600 msec	4.3
3E, 3D	800 msec	5.6
4E, 4D	1 sec	7.0
5E, 5D	No irradiation (control)	—

RESULTS

Enamel

In the control group the surface of the enamel showed that the regions with aprismatic enamel were more or less flat but that this alternated between the most external parts in the prisms and the interprismatic regions with an irregularity of different degrees (Fig. 1).

The specimens in groups 1E, 2E, and 3E were irradiated respectively by 500, 600, and 800 msec (Fig. 2) and morphologic and ultra-structural alterations were not noticed as compared to the characteristics of the control group.

The specimens in group 4E were irradiated for 1 s and showed significant morphologic alterations. A highly irregular surface was noted; the structure was molten, showing depressions similar to craters in the interior, and there was a loss of morphologic characteristics in much of the interprismatic regions as well as in the prismatic enamel (Fig. 3).

Dentine

The dentine showed typical tubular layering with peritubular portions that were mineralized and surrounded by an intertubular mass that was less mineralized and proportionally larger (Fig. 4).

FIG. 1. Electron micrography of the control group where the external prisms (black arrows), interprismatic regions (open arrows) and aprismatic enamel (*) are observed. ×500.

FIG. 2. Electron micrograph of the tooth exposed for 800 msec where the external prisms (black arrows), interprismatic regions (white arrows) and prismatic enamel (*) are observed with morphologic characteristics similar to the control group. $\times 1000$.

The specimens in groups 1D and 2D were irradiated for 500 and 600 msec, respectively. Apparently, no modification of the dentine structure was observed and the morphology of the tubules of the peritubular dentine and of the intertubular dentine was maintained (Fig. 4).

The specimens in group 3D were irradiated for 800 msec, and a tissue ablation and modification of the dentine surface was observed. There was evidence of alteration in the tubular structure, probably due to coalition and a recrystallization of

FIG. 3. Electron micrograph of the tooth exposed for 1 sec where the surface of the enamel observed is modified and irregular, as if molten, showing depressions similar to craters (black arrow) in the interior. $\times 2000$.

FIG. 4. Electron micrograph of the dentine from the group exposed for 600 msec showing the dentine tubules (black arrows), their organized form, lengthwise and apparently parallel, limited by a peritubular portion which is more uniform and compact (white arrows) and immersed in an intertubular mass which is less uniform and compact (*). $\times 1000$.

the dentine, furrows in several conflicting directions with an appearance similar to mineralized crystals on the ridges. However, some kept the original characteristics of the tubules of the peritubular dentine (Fig. 5).

The specimens in group 4D were irradiated for 1s and a higher level of modification to the dentine surface were observed; the characteristics of the dentine tubules were no longer identifiable (Fig. 6). This was probably due to a larger coalition and recrystallization of the dentine.

FIG. 5. Electron micrograph of the dentine from the group exposed for 800 msec where tecidual ablation, with evident disarrangement in the tubular structure, is observed (white stars) showing the tubules extending in several directions (black arrows). $\times 2000$.

FIG. 6. Electron micrography of the dentine for 1 sec, where the surface is observed modified with a larger disarrangement of the tubular structure without the identifiable morphologic characteristics of the dentine tubules. $\times 2000$.

DISCUSSION

Use of the laser in dentistry has inspired countless research publications and has had promising results concerning new technique development and clinical procedures.^{2,3,6,26,27} We can verify that conventional CVL radiation has a useful application in medicine, specifically in dermatology, but research has focused its application to soft tissue and has not expanded to the field of dentistry.^{23–25,29,31}

High-power lasers used in odontological clinics are argon, CO_2 , Nd:YAG, Ho:YAG, and ER:YAG. Authors have shown that the CVL is a possible substitute for the argon laser in the medical field through comparative research.^{21,22,30} This has provoked the curiosity of consulting authors, who have used argon laser radiation in mineralized dental tissues.

Renneboog-Squilbin et al.³² verified that the temperature increase in the dental pulp chamber is always smaller when the crown is exposed to the argon laser as compared to when a high-speed diamond drill is used under refrigeration or when compared with the immersion of the tooth in hot water (54–55°C). Still, with the argon laser, Westerman et al.³³ related an increased resistance to the enamel and decreased formation of caries *in vitro*. Tanji and Matsumoto⁵ found carbonization zones, crystal coalition, on the surface of the dentine and a closing of dentine tubules. Westerman et al.³⁴ found irregular adherent residues of a globular nature and more removal of surface material and the smear layer after irradiation.

One of the principal procedural concerns in dentistry is the potential for excessive heating of the enamel and/or dentine, reaching the pulp, which could cause irreversible damage when the temperature is elevated 11°C above normal. Several authors have studied the temperature increase in the pulp or in the dental pulp chamber when different kinds of lasers are used.^{8,9,11,14,16,18,19,35}

A substitution to the CVL can be ventured. The prototype laser used in our work showed another great advantage over

the conventional CVL in that the operating temperature is about five times lower. Perhaps, with further research, it would be possible to show that use at an even lower temperature could also be successful.

In the literature, various lasers with different powers were used on two kinds of mineralized dental tissue, enamel and dentine. In our research, a CVL laser was used on dental tissue and the initial power was fixed at 7 W with variation only in exposure time.

We should note that in the enamel as well as in the dentine morphologic alterations were not observed at exposure times of 500 and 600 msec. Only when laser exposure was at 800 msec and 1 sec, microscopic and ultra-structural morphologic alterations were observed in the enamel and dentine. The modifications to the surface of the enamel and/or dentine produced by the irradiation from different kinds of lasers can be the result of denaturation of the collagen matrix followed by chemical changes in the inorganic matrix of the mineralized tissues.

An important difference among lasers is the energy density variation between the wavelengths of the CVL, argon, Nd:YAG, and CO_2 . These variations produce different modifications in the enamel and in the dentine indicating that the absorption of each wavelength is different in the mineralized structures.

This being the case, exposure time and the level of power are of importance. High-energy lasers propitiate in the enamel the appearance of craters, carbonization, cracking, granules, coalition, recrystallization and prismatic alterations. This is related in research with different kinds of laser radiations such as CO_2 ,^{1,11,13} Er:YAG, Ho:YAG,² and argon.^{33,34} We also observed these alterations in the enamel with an exposure time of a 1-sec application of the CVL.

As in the enamel, there is also a dependence on the exposure time and power used when applied to the dentine. High-energy lasers propitiate the appearance of morphologic alterations such as carbonized areas, craters, cracking, coalition, recrystallization, and the presence of disorganized and/or sealed tubules. These effects are related in studies done with CO_2 and argon laser radiation.^{4,5,13,33–35} We also observed these alterations in the dentine at exposure times of 800 msec. When the exposure time was 1 sec, the alterations were more intense, with larger incidence of coalition and recrystallization.

Once it is verified that the CVL has the capacity of changing microscopic and ultra-structurally the morphology of mineralized dental tissues, both in the enamel and dentine, we can affirm that our research is the first step in further studying the effects of this kind of radiation in dentistry. With this base, research done by other authors can be relevant to the evolution of CVL use in dentistry.

We therefore propose that more research should be done to develop an expanded evaluation of the effects of the CVL. In this research, exposure time and power binomial should be further investigated to find the most adequate setting for different kinds of tissues and for each therapeutic purpose. Several authors state that the temperature increment in soft tissues should also be considered, mostly in the pulp, as another important variable to be evaluated for only then can parameters be established that will enable correct indication in the odontological practice.

Finally, regarding the use of the laser in dentistry, no matter how much progress seems to have been made, it is still incipi-

ent and restricted from numerous other applications in wider fields of dentistry.

CONCLUSION

We believe we can conclude that the enamel group exposed to 1 sec of radiation by the CVL laser showed an evident ultrastructural modification with an appearance of crater-like depressions and irregular structures of molten enamel. At irradiation times of 500, 600, and 800 msec, there wasn't any alteration to the structure of the enamel. In the dentine group exposed for 1-sec, tissue coalition and a regional loss of morphologic characteristics were shown. The group irradiated with 800 msec showed tissue ablation and partial loss of the morphologic structures, and in the groups with 500 and 600 msec of exposure, there was no alteration of the structure of the dentine. The results showed that irradiation with CVL can promote morphologic changes in the enamel as well as in the dentine thus demonstrating the need for new studies to establish a safe protocol for its use in the odontological practice.

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Address reprint requests to:

Walter Niccoli-Filho, D.D.S., Ph.D.

Academic Group Studies and Research with Laser in Dentistry

Sao Paulo State University

Av. Francisco Jose Longo, 777

12245-000 Sao Jose dos Campos, SP, Brazil

E-mail: niccoli@fosjc.unesp.br