Thermal Alteration and Morphological Changes of Sound and Demineralized Primary Dentin After Er:YAG Laser Ablation

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KEY WORDS temperature; SEM; decidous teeth; laser

ABSTRACT The purpose of this study was to assess the influence of Er:YAG laser pulse repetition rate on the thermal alterations occurring during laser ablation of sound and demineralized primary dentin. The morphological changes at the lased areas were examined by scanning electronic microscopy (SEM). To this end, 60 fragments of 30 sound primary molars were selected and randomly assigned to two groups ($n = 30$); namely A sound dentin (control) and B demineralized dentin. Each group was divided into three subgroups ($n = 10$) according to the employed laser frequencies: I–4 Hz; II–6 Hz, and III–10 Hz. Specimens in group B were submitted to a pH-cycling regimen for 21 consecutive days. The irradiation was performed with a 250 mJ pulse energy in the noncontact and focused mode, in the presence of a fine water mist at 1.5 mL/min, for 15 s. The measured temperature was recorded by type K thermocouples adapted to the dentin wall relative to the pulp chamber. Three samples of each group were analyzed by SEM. The data were submitted to the nonparametric Kruskal-Wallis test and to qualitative SEM analysis. The results revealed that the temperature increase did not promote any damage to the dental structure. Data analysis demonstrated that in group A, there was a statistically significant difference among all the subgroups and the temperature rise was directly proportional to the increase in frequency. In group B, there was no difference between subgroup I and II in terms of temperature. The superficial dentin observed by SEM displayed irregularities that augmented with rising frequency, both in sound and demineralized tissues. In conclusion, temperature rise and morphological alterations are directly related to frequency increment in both demineralized and sound dentin. *Microsc. Res. Tech. 75:126–132, 2012.*

INTRODUCTION

New technologies have been developed to replace the conventional restorative procedure, to obtain a more selective and conservative therapy (Hibst and Keller, 1989; Keller and Hibst, 1995; Raucci-Neto et al., in press; Yazici et al., 2010) that is also more comfortable to the patient, and often eliminate the need for anesthesia (Chaiyavej et al., 2000). The reported advantages of laser technology compared to conventional high-speed rotatory instrumentation include, apart from the possibility of treatment without local anesthesia, elimination of stress factors such as vibration, pressure, and noise, which cause anxiety in patients, especially children (Chaiyavej et al., 2000; Keller and Hibst, 1997; Liu et al., 2006a).

Many researchers have investigated the efficiency of the Er:YAG laser for dental applications, such as cavity preparation (Attrill et al., 2004; Bertrand et al., 2006; Chinelatti et al., 2006; Contente et al., in press; Dostalová et al., 1996; Gimbel, 2000; Raucci-Neto et al., 2007; Takamori et al., 2003), periodontal treatment (Crespi et al., 2006), and superficial treatment for caries prevention (Correa-Afonso et al., 2010; Liu et al., 2006b). This laser has an active yttrium-aluminum-garnet crystal doped with erbium ions and emits energy of 2.94 μm wavelength, which coincides with the maximum water and OH— absorption peak in tooth hard tissues. Dentin ablation by Er:YAG laser occurs when the organic components of the tissues absorb the radiated energy, causing water and OH— to vaporize (Hibst and Keller, 1989). A small portion of this energy is not consumed in the ablation process, causing heating of the dental structures (Hibst and Keller, 1989). Among Er:YAG laser parameters, pulse frequency deserves attention because it is directly related to temperature increment in tissues and dental pulp (Armengol et al., 2000; Attrill et al., 2004; Dostalová et al., 1998; Raucci-Neto et al., 2007; Takamori et al., 2003). According to Zach and Cohen (1965), temperature rises above 5.5°C for 1 min may promote irreversible pulp damage. However, thermal

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Received 25 January 2011; accepted in revised form 24 April 2011
DOI 10.1002/jemt.21034
Published online 14 July 2011 in Wiley Online Library (wileyonlinelibrary.com).

variations may be minimal if the Er:YAG laser parameters are adjusted to the ideal cooling system (Correa-Afonso et al., 2008; Hibst and Keller, 1989; Matsumoto et al., 1996; Raucci-Neto et al., 2007).

The ablation rate depends on the dental tissues' water content (Armengol et al., 1999; Colucci et al., 2009; Hibst and Keller, 1989; Hossain et al., 1999; Jelinková et al., 1996; Mercer et al., 2003) therefore, demineralized dentin ablation is greater than sound dentin ablation and varies according to the tissue's water content (Meister et al., 2006).

Several studies (Corona et al., 2007; Dostalová et al., 1998; Hibst and Keller, 1989; Hossain et al., 1999; Paghdiwala et al., 1993; Palma-Dibb et al., 2002) have confirmed the Er:YAG laser efficiency during cavity preparation in the case of permanent teeth. Studies on deciduous teeth are still scarce, and the methodologies and parameters employed in this case are largely diverse, which prevents researchers from reaching conclusions about cavity uniformity (Kato et al., 2003; Kornblite et al., 2008; Krause et al., 2008; Monghini et al., 2004), and the thermal effect produced by this type of laser (Castillho et al., 2007; Contente et al., in press). There are morphological and structural differences between primary and permanent tooth dentin, which may interfere with both the ablation intensity and the temperature reached after irradiation. Among these differences thickness, permeability, numerical tubular density, and available area of intertubular dentin should be highlighted (Hirayama et al., 1986; Sumikawa et al., 1999).

In this context, the aim of this in vitro study was to assess the influence of Er:YAG laser pulse repetition rate on the thermal alterations occurring during laser ablation of sound and demineralized primary dentin. The morphological changes at the lased areas were analyzed by scanning electronic microscopy (SEM).

MATERIALS AND METHODS

This in vitro study was approved by the Research and Ethics Committee of the Ribeirão Preto School of Dentistry, University of São Paulo.

Experimental Design

The factors under study were the irradiated primary dentin substrate at two levels; namely sound and demineralized dentin, and the Er:YAG laser pulse repetition rates used for irradiation at three levels: 4, 6, and 10 Hz. The experimental units consisted of 60 dentin blocks obtained from the deciduous molars. The specimens were randomly assigned to two groups, according to the irradiated substrate, and each group was divided into three subgroups ($n = 10$), depending on the employed frequency. The response variables were temperature alteration (°C) and morphological analysis through SEM.

Sample Preparation

The 30 sound deciduous molars used in this study were selected from the Ribeirão Preto Dentistry School Human Tooth Bank. The teeth were thoroughly cleaned with a hand scaler and rubber cup/pumice prophylaxis and were stored in a 0.4% sodium azide solution at 4°C until use.

When necessary, the roots were sectioned 2 mm below the cementoenamel junction by means of a water-cooled diamond saw, using a sectioning machine (Minitom, Struers A/S, Copenhagen, DK-2610, Denmark). Next, crowns were fixed with wax in Plexiglass® plates and bisected longitudinally in a mesiodistal direction using a double-faced diamond disk (KG Sorensen, 7015, Barueri-SP, Brasil) mounted on a low-speed handpiece, which provided 60 fragments with standard dimensions of 4 mm height × 4 mm width. Afterward, the fragments were individually fixed with wax in a cylindrical Plexiglass® and taken to a polishing machine (Politriz DP-9U2, Panambi/Struers, A/S Copenhagen, DK-2610, Denmark) for grinding with silicon carbide paper disks of decreasing granulation (# 280 - # 1200, Norton/Saint-Gobain Abrasives, Guarulhos-SP, 07111-150, Brazil), under refrigeration. This procedure was accomplished until dentin with flat surfaces was achieved. The dentin surface was exposed using a standard 2.0 mm thickness.

Demineralized dentin group ($n = 30$) sample were submitted to an in vitro pH cycling model as proposed by Serra and Cury (1992), but the experimental period was modified based on a pilot study. The fragments were covered with acid-resistant nail varnish, so that only 9 mm^2 area dentin remained exposed. The square area was bound using a tape of predetermined size. The samples were individually immersed in 150 mL of demineralizing solution (DES) (2 mmol/L calcium, 2 mmol/L phosphate, and 75 mmol/L acetate at pH4.6) for 16 h. After this period, they were removed and washed with deionized water for 10 s and slightly dried with paper towels. Then, the samples were immersed for 8 h in the same amount of remineralizing solution (RE) (1.5 mmol/L calcium, 0.9 mmol/L phosphate, 150 mmol/L potassium chloride, and 20 mmol/L cacodilate buffer at pH 7.0), which presents a mineral saturation degree similar to that of saliva and similar to the one proposed by Ten Cate and Duijsters (1982). The entire procedure was performed in an oven at 37°C. The DES and RE solutions were replaced daily during a 21-day experimental period, so it was possible to obtain demineralization depth of ~ 1.0 mm.

Cavity Preparation and Temperature Measurement

During the study, the specimens were kept in distilled water at 4°C and removed from water 2 h before laser irradiation. Before cavity preparation and temperature measurements, one small orifice was made with a #1/2 low-speed carbide bur on the opposed surface corresponding to the roof of the pulp chamber, to which the thermocouple was attached.

All measurements were performed in a temperature/humidity-controlled room, at a constant temperature of 21°C and 30% relative humidity. The fragments were divided into three subgroups ($n = 10$) according to the laser repetition rate (4, 6, or 10 Hz). The cavities were prepared with a 2.94-μm wavelength laser (KaVo Key 2, KaVo Dental GmbH, KG, Bismarckring 39, 88396, Biberach, Germany) using the noncontact and focused mode for 15 s, in the presence of a fine water mist at 1.5 mL/min. The laser parameters are summarized in Table 1 (Ortolan et al., 2009). The irradiation distance of 12 mm was standardized using a custom-made appa-

TABLE 1. Laser parameters

	4 Hz	6 Hz	10 Hz
Energy per Pulse	250 mJ	250 mJ	250 mJ
Energy Density	88.4 J/cm^2	88.4 J/cm^2	88.4 J/cm^2
Average Power Output	1 W	1.5 W	2.5 W
Total energy	15 J	22.5 J	37.5 J

ratus consisting of a holder that positioned the handpiece in such a way that the laser beam was delivered perpendicular to the specimen surface at a constant working distance from the target site, and a semi adjustable base, to which the specimen was fixed with wax. One previously trained operator handled the apparatus micrometer screws in such a way that the semi adjustable base with the specimen was alternately moved right-to-left and forward-to-backward, thereby allowing the laser beam to provide accurate irradiation of the entire enamel site.

Before the beginning of the procedure, the type K thermocouple attached to the dentin was connected to a portable USB-based data acquisition module (NI USB-9211A, National Instruments, Austin, TX) with four channels of 24-bit resolution. After temperature stabilization within the set, the initial temperature was recorded. For each specimen, the temperature was registered from the start of the laser irradiation until the end of cavity preparation or temperature stabilization. The equipment was calibrated with 0.2°C accuracy and 0.6 s response time. The "Measurement and Automation Software and VI Logger Lites" connected to a computer configured for temperature reading was employed during data acquisition.

Morphological Characterization

After the temperature measurement, three specimens of each group were selected for morphological cavity characterization by SEM. Specimen dehydration was performed in increasing series of ethanol at 25, 50, and 75% for 20 min each, 95% for 30 min, and 100% for 60 min. Next, the specimens were immersed in HMDS solution (hexamethyldisilazane) for 10 s. Each group had its samples fixed on stubs with the treated surface turned to the upper surface for analysis. A Scanning Electronic Microscope (Phillips, XL30 FEGm Eindhoven, Holland) operating at 20 KV was employed. The entire surface was scanned to characterize the resulting cavity.

Data Analysis

For statistical analysis of temperature measurements, means and standard deviations were calculated, and data were analyzed by the nonparametric Kruskal-Wallis test using a factorial design with pulse repetition rate and substrate as independent factors. The Mann-Whitney test was employed for means comparison ($P < 0.05$). SEM analysis findings were not statistically analyzed, because the objective of this analysis was to perform a visual and qualitative comparison of the different experimental conditions proposed in the study.

RESULTS

The means, standard deviations, and medians of each group, as well as their interaction are listed in Table 2. Data analysis demonstrated that there was statistically significant difference between the frequency variation factor and the temperature mean values. Overall, the 10 Hz frequency resulted in higher mean temperature compared to other frequencies (Fig. 1). In case of the sound substrate, there were differences among all the frequencies; however, no difference was found between the frequencies 4 and 6 Hz for the demineralized substrate (Table 2).

TABLE 2. Means, standard deviations, and medians of temperature rise during cavity preparation with Er:YAG laser in sound and demineralized deciduous dentin (°C)

Substrate Frequency	Group A Sound Dentin	Group B Demineralized Dentin
I–4 Hz	−0.036 ± 0.11/−0.049 a	−0.060 ± 0.87/−0.056 A
II–6 Hz	0.071 ± 0.80/0.049 b	0.012 ± 0.14/0.008 A
III–10 Hz	0.979 ± 0.92/0.968 c	0.458 ± 0.48/0.354 B

Same letters equal statistical similarity—comparison in the column.

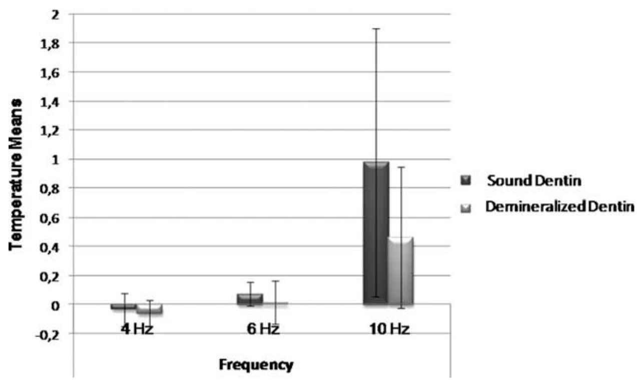

Fig. 1. Median of temperature values (°C) of each group and subgroup.

SEM analysis revealed dentin ablation with nonselective pattern, which culminate in irregular topography with open dentinal tubules and the absence of smear layer (Figs. 2–4). Irregularities in the laser-prepared cavities increased proportionally with rising repetition rate, mainly because greater intertubular dentin ablation occurred, which led to greater evidence of peritubular dentin protusions. Small cracks were also detected on the surface (Figs. 2 and 3).

The groups irradiated with 10 Hz frequency exhibited decreased dentinal tubules lumen as well as more fissures and cracks, in addition to an amorphous pattern of irradiated dentin (Fig. 4). The sound and demineralized dentin irradiated with 10 Hz laser were similar, probably due to the complete removal of demineralized dentin achieved by using this frequency.

DISCUSSION

Laser has emerged in Dentistry as a promising tool for cavity preparation and selective carious tissue removal. However, its major inconvenience is lased tissue heating during ablation, which can cause morphological and microstructural changes as well as irreversible pulp damage (Hibst and Keller, 1989).

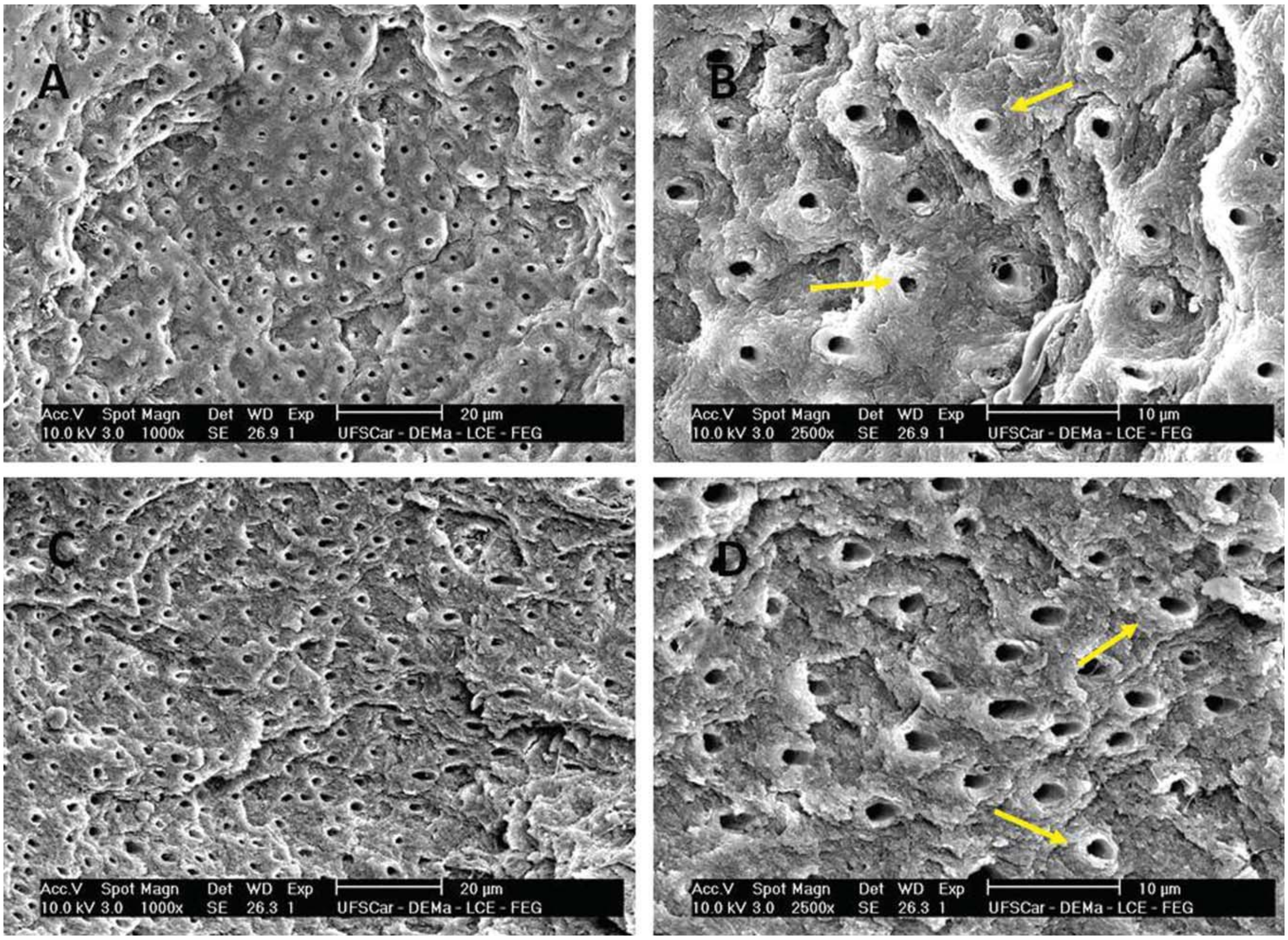

Fig. 2. Irradiated primary dentin surface using 4 Hz of frequency. Sound dentin: (**A**) ×1000 and (**B**) ×2500; Irregular topography with open dentinal tubules, absence of smear layer, and greater evidence of peritubular dentin. Demineralized dentin: (**C**) ×1000 and (**D**) ×2500; Nonselective pattern of dentin ablation, open dentinal tubules, homogeneous, and flat topography without cracks. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

Studies evaluating Er:YAG laser irradiation on primary dentin and relating possible temperature rise with morphological alterations on the substrate surface are scarce in the literature, which makes comparison of the methodologies and results of this work difficult. Moreover, the morphological and structural characteristics of deciduous teeth differ from those of permanent teeth and may interfere in the ablation mechanism, thereby resulting in increased or decreased temperature upon Er:YAG laser irradiation (Castilho et al., 2007).

Considering these differences, Hirayama et al. (1986) and Ruschel et al. (1996) have reported that the peritubular dentin thickness is $\sim$ 2–5 times thicker in primary compared to permanent teeth. Sumikawa et al. (1999) have emphasized that the numerical density of dentinal tubules is greater in deciduous teeth, so there is a decrease in the available intertubular dentin area. These differences in the composition of each tooth type and the major organic characteristics of deciduous teeth influence the parameters employed for primary and permanent teeth irradiation (Borsatto et al., 2006; Celiberti et al., 2006; Monghini et al., 2004; Wanderley et al., 2005) and may result in different temperature behaviors in the surrounding tissues after irradiation.

The results of this study have demonstrated that there are significant differences in terms of temperature changes during ablation of both substrates, sound, and demineralized, only at 10 Hz frequency. These findings corroborate those of several studies reporting that increasing thermal alterations to the irradiated substrate are related to rising of pulse repetition rates (Armengol et al., 2000; Geraldo-Martins et al., 2005; Hibst and Keller, 1989; Keller and Hibst, 1989; Li et al., 1992; Mehl et al., 1997). The temperature rise in demineralized dentin showed a tendency of was lower values than sound tissue, which probably be influenced by carious dentin features. In spite of this study used in vitro simulation by pH cycling model for demineralized dentin, which does not have the same morphological characteristics as the carious dentin, since in the latest contamined and affected tissue can be observed, the in vitro demineralized dentin tissue presents demineralization, disorganization, and that also contains a high volume of water. In theory, the ablation rate is directly related to the amount of water present

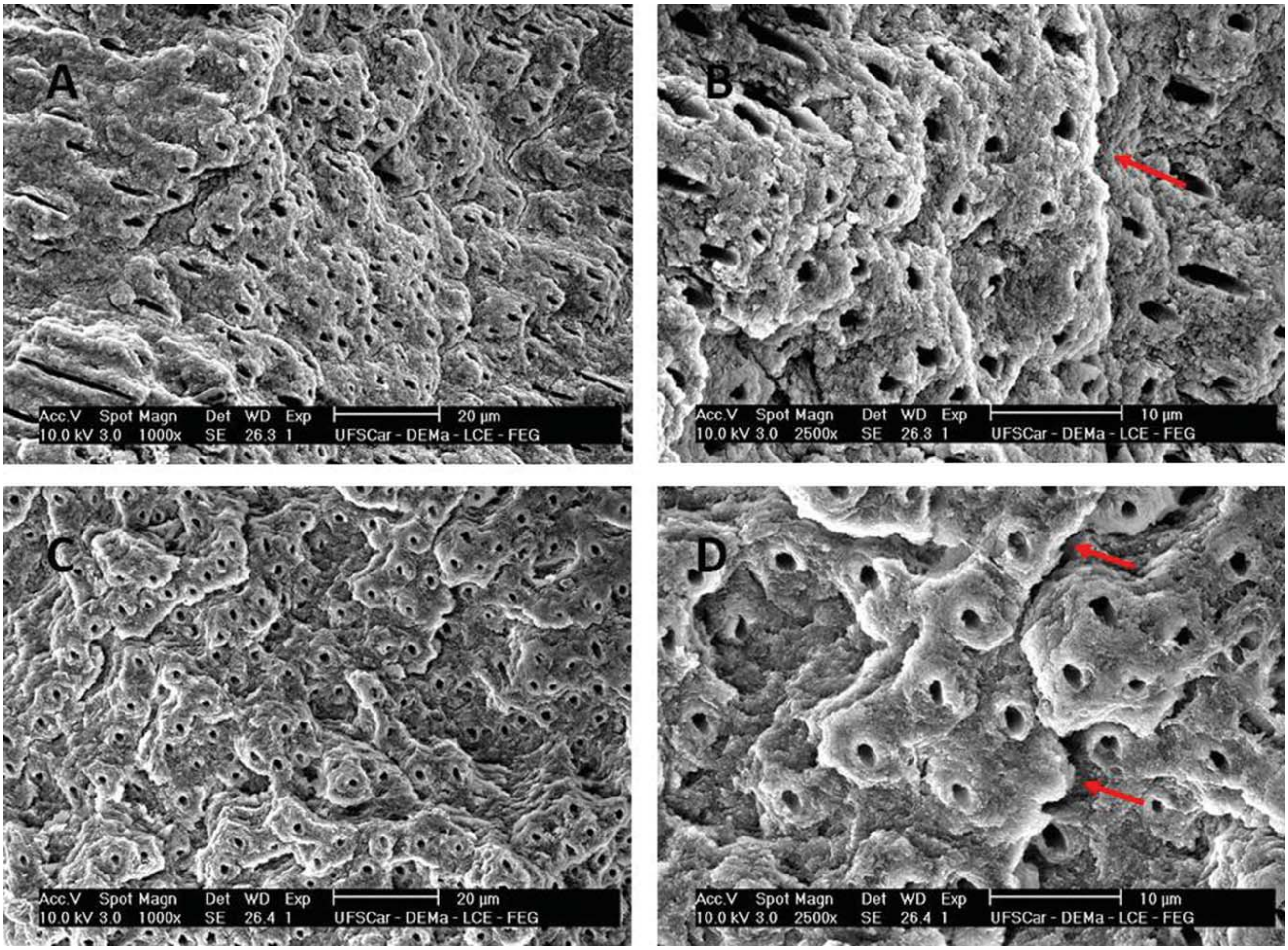

Fig. 3. Irradiated primary dentin surface using 6 Hz of frequency. Sound dentin: (**A**) ×1000 and (**B**) ×2500; Small cracks, greater superficial irregularities and evidence of peritubular dentin than the groups using 4 Hz. Demineralized dentin: (**C**) ×1000 and (**D**) ×2500; Small cracks, some occluded dentinal tubules and superficial irregularities. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

in the substrate (Meister et al., 2006). Bearing this in mind, the carious tissue irradiation may consume most of the energy from the ablation process, so that just a small portion of the energy dissipates and produces temperature rise. This in turn, can cause lower heating of adjacent tissues compared to sound dentin irradiation (Armengol et al., 2000). These characteristics of sound and carious dentin from primary teeth warn of the need for determining appropriate parameters for utilization of Er:YAG laser on different substrates.

Pulse frequency is the parameter that most influences the temperature rise during ablation. Because of the increase in the laser pulse repetition rate, more energy is deposited in dental tissue per time unit, thus providing greater number of micro explosions, and consequently removing more substrate (Corona et al., 2007; Hibst and Keller, 1989). In deciduous teeth, 250 mJ/4 Hz parameters are considered effective for sound dentin tissue ablation (Ortolan et al., 2009). The energy applied in this study for demineralized and sound dentin removal was 250 mJ with variable frequency rates of 4, 6, and 10 Hz, using the focused mode and 12 mm distance. The results showed that there was a greater temperature enhancement in the frequency case of 10 Hz for both substrates, and that there were no dentin demineralization differences between 4 and 6 Hz. Therefore, it is possible to indicate with certainty that cavity preparations can be performed 250 J/4 Hz parameters in primary teeth, since sound and demineralized tissue will be ablated without temperature elevation to critical levels.

The results obtained from the groups irradiated with 10 Hz in both substrate groups revealed greater thermal alteration, but the temperature rise did not reach 1.0°C, which is well below the critical value of 5.5°C recommended by Zach and Cohen (1965). However, the morphological analysis performed in this study showed that these irradiated groups presented greater irregularities compared to the other groups, along with an amorphous pattern for the irradiated dentin various dentinal tubules obstruction. Moreover, the both substrate groups presented similar morphological changes. These findings lead to the assumption that

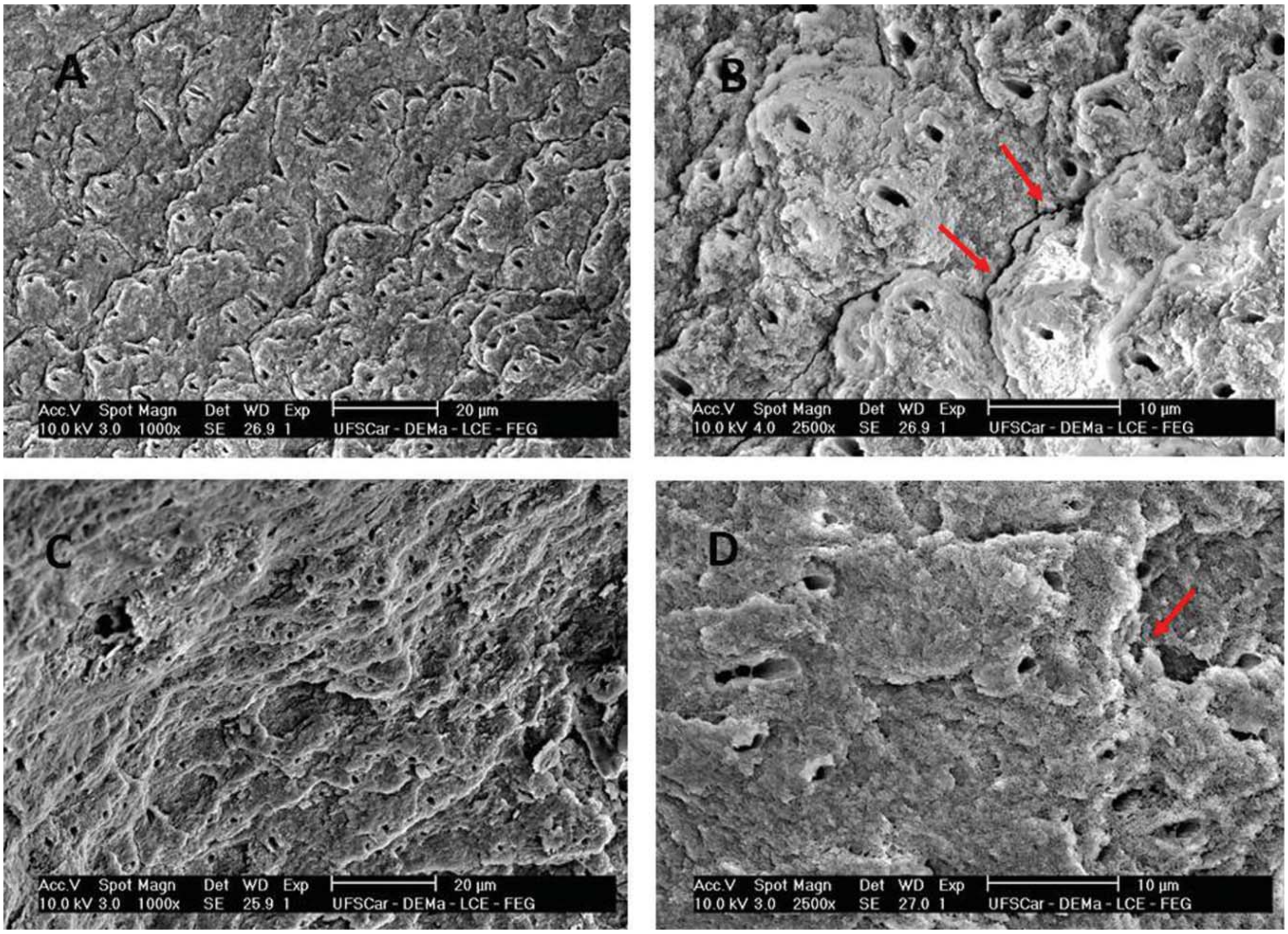

Fig. 4. Irradiated primary dentin surface using 10 Hz of frequency. Sound dentin: (**A**) ×1000 and (**B**) ×2500; Irregular surface, cracks presence and considerable reduction of dentin tubules diameter. Demineralized dentin: (**C**) ×1000 and (**D**) ×2500; Presence of cracks and amorphous aspect of irradiated dentin. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

there is complete carious tissue removal at a 10 Hz frequency, and possible sound tissue removal.

The morphological pattern found in the dentin after irradiation with Er:YAG laser is characterized by an irregular surface secondary to the increased intertubular dentin ablation rate. This resulted in protrusion of peritubular dentin. Increased intertubular dentin ablation is probably a consequence of its higher percent organic constituents, collagen fibers, and water content. It also can be observed that as the pulse repetition rates increased from 4 to 6 Hz, these morphological changes became more evident. These results are consistent with those of permanent teeth found in the literature (Bertrand et al., 2006; Corona et al., 2007; Hossain et al., 2003; Monghini et al., 2004; Raucci-Neto et al., 2007; Souza-Gabriel et al., 2009).

The results of this study indicate that the use of Er:YAG laser using the evaluated parameters does not significantly change the temperature, once the highest mean value achieved for temperature rise was around 1°C, which is far from the critical value of 5.5°C. However, for this laser to be applied in the clinical setting, further studies should be performed. Assessment of the adhesive procedures on these surfaces modified by laser must be accomplished, so that new technology can be finally added as an extra feature in dental offices.

REFERENCES

Armengol V, Jean A, Rohanizadeh R, Hamel H. 1999. Scanning electron microscopic analysis of diseased and healthy dental hard tissues after Er:YAG laser irradiation: In vitro study. J Endod 25:543–546.

Armengol V, Jean A, Marion D. 2000. Temperature rise during Er:YAG and Nd:YAG laser ablation of dentin. J Endod 26:138–141.

Attrill DC, Davies RM, King TA, Dickinson MR, Blinkhorn AS. 2004. Thermal effects of the Er:YAG laser on a simulated dental pulp: A quantitative evaluation of the effects of a water spray. J Dent 32:35–40.

Bertrand MF, Semez G, Leforestier E, Muller-Bolla M, Nammour S, Rocca JP. 2006. Er:YAG laser cavity preparation and composite resin bonding with a single-component adhesive system: Relationship between shear bond strength and microleakage. Lasers Surg Med 38:615–623.

Borsatto MC, Corona SA, Chinelatti MA, Ramos RP, de Sá Rocha RA, Pecora JD, Palma-Dibb RG. 2006. Comparison of marginal microleakage of flowable composite restorations in primary molars prepared by high-speed carbide bur. Er:YAG laser, and air abrasion. J Dent Child (Chic) 73:122–126.

Castilho MS, de Souza-Gabriel AE, Marchesan MA, Floriam LJ, Sousa-Neto MD, Correa Silva-Sousa YT. 2007. Temperature changes in the deciduous pulp chamber during cavity preparation with the Er:YAG laser. J Dent Child (Chic) 74:21–25.
Celiberti P, Francescut P, Lussi A. 2006. Performance of four dentine excavation methods in deciduous teeth. Caries Res 40:117–123.
Chaiyavej S, Yamamoto H, Takeda A, Suda H. 2000. Response of feline intradental nerve fibers to tooth cutting by Er:YAG laser. Lasers Surg Med 27:341–349.
Chinelatti MA, Ramos RP, Chimello DT, Milori Corona AS, Pecora JD, Palma Dibb RG. 2006. Influence of Er:YAG laser on cavity preparation and surface treatment in microleakage of composite resin restorations. Photomed Laser Surg 24:214–218.
Colucci V, do Amaral FL, Pécora JD, Palma-Dibb RG, Corona SA. 2009. Water flow on erbium:yttrium-aluminum-garnet laser irradiation: Effects on dental tissues. Lasers Med Sci 24:811–818.
Contente MM, de Lima FA, Galo R, Pécora JD, Bachmann L, Palma-Dibb RG, Borsatto MC. Temperature rise during Er:YAG cavity preparation of primary enamel. Lasers Med Sci, in press.
Corona SAM, Souza AE, Chinelatti MA, Borsatto MC, Pecora JD, Palma-Dibb RG. 2007. Effect of energy and pulse repetion rate of Er:YAG laser on dentin in ability and morphological analysis of the laser-irradiated surface. Photomed Laser Surg 25:26–33.
Correa-Afonso AM, Pécora JD, Palma-Dibb RG. 2008. Influence of pulse repetition rate on temperature rise and working time during composite filling removal with the Er:YAG laser. Photomed Laser Surg 26:221–225.
Correa-Afonso AM, Ciconne-Nogueira JC, Pécora JD, Palma-Dibb RG. 2010. Influence of the irradiation distance and the use of cooling to increase enamel-acid resistance with Er:YAG laser. J Dent 38:534–540.
Crespi R, Barone A, Covani U. 2006. Er:YAG laser scaling of diseased root surfaces: A histologic study. J Periodontol 77:218–222.
Dostalová T, Jelinkova H, Krejsa O, Hamal H. 1996. Evaluation of the surface changes in enamel and dentin due to possibility of thermal overheating induced by Erbium:YAG laser radiation. Scanning Microsc 10:285–290.
Dostalová T, Jelinková H, Kucerová H, Krejsa O, Hamal K, Kubelka J, Procházka S. 1998. Non contact Er:YAG laser ablation. J Clin Med Surg 16:273–282.
Hibst R, Keller U. 1989. Experimental studies of the application of the Er:YAG laser on dental hard substances: I. Measurement of the ablation rate. Lasers Surg Med 9:338–344.
Hirayama A, Yamada M, Miake K. 1986. Na electron microscopic study on dentinal tubules of human deciduos teeth. Shikwa-Gakuho 86:1021–1031.
Hossain M, Nakamura Y, Kimura Y, Nakamura G, Matsumoto K. 1999. Ablation depths and morphological changes in human enamel and dentin after Er:YAG laser irradiation with or without water mist. J Clin Laser Med Surg 17:105–109.
Hossain M, Nakamura Y, Murakami Y, Yamada Y, Matsumoto K. 2003. A comparative study on compositional changes and Knoop hardness measurement of the cavity floor prepared by Er:YAG laser irradiation and mechanical bur cavity. J Clin Laser Med Surg 21:29–33.
Geraldo-Martins VR, Tanji EY, Wetter NU, Nogueira RD, Eduardo CP. 2005. Intrapulpal temperature during preparation with the Er:YAG: an in vitro study. Photomed Laser Surg 23:182–186.
Gimbel CB. 2000. Hard tissues laser procedures. Dent Clin North Am 44:931–953.
Kato J, Moriya K, Jayawardena JA, Wijeyeweera RL. 2003. Clinical application of Er:YAG laser for cavity preparation in children. J Clin Laser Med Surg 21:151–155.
Keller U, Hibst R. 1989. Experimental studies of the application of the Er:YAG laser on dental hard substances: II. Light microscopic and SEM investigations. Lasers Surg Med 9:345–351.
Keller U, Hibst R. 1995. Er:YAG laser effects on oral hard and soft tissues. In: Miserandino LJ, Pick RM, editors. Lasers in Dentistry. Singapore: Quintessence Publishing. pp.161–172.
Keller U, Hibst R. 1997. Effects of Er:YAG laser in caries treatment: A clinical pilot study. Lasers Surg Med 20:32–38.
Kornblit R, Trapani D, Bossù M, Muller-Bolla M, Rocca JP, Polimeni A. 2008. The use of Erbium:YAG laser for caries removal in paediatric patients following minimally invasive dentistry concepts. Eur J Paediatr Dent 9:81–87.
Krause F, Braun A, Lotz G, Kneist S, Jepsen S, Eberhard J. 2008. Evaluation of selective caries removal in deciduous teeth by a fluorescence feedback-controlled Er:YAG laser in vivo. Clin Oral Investig 12:209–215.
Li ZZ, Code JE, Van De Merwe WP. 1992. Er:YAG laser ablation of enamel and dentin of human teeth: Determination of ablation rates at various fluences and pulses repetition rates. Laser Surg Med 12:625–630.
Liu JF, Lai YL, Shu WY, Lee SY. 2006a. Acceptance and efficiency of Er:YAG laser for cavity preparation in Children. Photomed Laser Surg 24:489–493.
Liu J, Liu Y, Stephen HYC. 2006b. Optimal Er:YAG laser energy for preventing enamel demineralization. J Dent 34:62–66.
Matsumoto K, Nakamura Y, Mazeki K, Kimura Y. 1996. Clinical dental application of Er:YAG laser for class V cavity preparation. J Clin Laser Med Surg 14:123–127.
Mehl A, Kremers L, Salzmann K, Hickel R. 1997. 3D volume-ablation rate and thermal side effects with the Er:YAG and Nd:YAG laser. Dent Mater 13:246–251.
Meister J, Franzen R, Forner K, Grebe H, Stanzel S, Lampert F, Apel C. 2006. Influence of the water content in dental enamel and dentin on ablation with erbium YAG and erbium YSGG lasers. J Biomed Opt 11:34030.
Mercer CE, Anderson P, Davis GR. 2003. Sequential 3D X-ray microtomographic measurement of enamel and dentine ablation by an Er:YAG laser. Br Dent J 25:99–104.
Monghini EM, Wanderley RL, Pecora JD, Palma-Dibb RG, Corona SA, Borsatto MC. 2004. Bond strength to dentin of primary teeth irradiated with varying Er:YAG laser energies and SEM examination of the surface morphology. Lasers Surg Med 34:254–259.
Ortolan ASO, Torres CP, Gomes-Silva JM, Oliveira MAHM, Pécora JD, Palma-Dibb RG, Borsatto MC. 2009. Effect of erbium-doped yttrium aluminium garnet laser parameters on ablation capacity and morphology of primary dentin. Photomed Laser Surg 27:885–890.
Paghdiwala AF, Vaidyanathan TK, Paghdiwala MF. 1993. Evaluation of erbium:YAG radiation of hard dental tissues: Analysis of temperature changes, depth of cuts and structural effects. Scanning Microsc 7:989–997.
Raucci-Neto W, De Castro LM, Correa-Afonso AMda Silva RS, P'ecora JD, Palma-Dibb RG. 2007. Assessment of thermal alteration during class V cavity preparation using the Er:YAG laser. Photomed Laser Surg 25:281–286.
Raucci-Neto W, Chinelatti MA, Ito IY, Pécora JD, Palma-Dibb RG. Influence of Er:YAG laser frequency on dentin caries removal capacity. Microsc Res Tech, in press.
Ruschel HC, Souza MAL, Fossati ACM, Chevitarese O, Souza IPR. 1996. Estrutura dentinaria decídua e permanente: princípios para uma conduta clínica racional. Rev Assoc Bras Odontol Nac 4:161–165.
Souza-Gabriel AE, Chinelatti MA, Pecora JD, Palma-Dibb RG, Corona SA. 2009. Dentin microhardness and subsurface morphology after Er:YAG laser cavity preparation using different parameters. J Dent Child (Chic) 76:58–66.
Sumikawa DA, Marshall GW, Gee L, Marshall SJ. 1999. Microstructure of primary tooth dentin. Pediatr Dent 21:439–444.
Takamori K, Furukawa H, Morikawa Y, Katayama T, Watanabe S. 2003. Basic study on vibrations during tooth preparations caused by high-speed drilling and Er:YAG laser irradiation. Lasers Surg Med 32:25–31.
Ten Cate JM, Djuisters PPE. 1982. Alternating demineralization e remineralization of artificial enamel lesions. Caries Res 16:201–210.
Wanderley RL, Monguini EM, Pecora JD, Palma-Dibb RG, Borsato MC. 2005. Shear bond strength to enamel of primary teeth irradiated with varying Er:YAG laser energies and SEM examination of the surface morphology: An in vitro study. Photomed Laser Surg 23:260–267.
Yazici AR, Baseren M, Gorucu J. 2010. Clinical comparison of bur- and laser-prepared minimally invasive occlusal resin composite restorations: Two-year follow-up. Oper Dent 35:500–507.
Zach L, Cohen G. 1965. Pulp response to externally applied heat. Oral Surg Oral Med Oral Pathol 19:515–530.