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The Use of Bur and Laser for Root Caries Treatment: A Comparative Study

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Clinical Relevance

The marginal seal of composite restorations placed in cavities prepared using an Er,Cr:YSGG laser is not satisfactory as a result of the presence of irregularities on the edge of the cavities and the difficulties associated with leaving a substrate free of caries.

Summary

This research analyzed the influence of bur and erbium, chromium:yttrium-scandium-gallium-garnet (Er,Cr:YSGG) laser caries removal on cavity characteristics and marginal seal of composite resin restorations. One hundred and forty human dental root samples were used. After *in vitro* root caries induction using *Streptococcus mutans*, the carious lesions were removed either by a conventional technique using burs (G1=control) or by using an Er,Cr:YSGG laser (λ=2.78 μm, 20 Hz, pulse duration≅140 μs, noncontact mode using a 600-μm tip) with the following power outputs: G2: 1.0 W; G3: 1.25 W; G4: 1.5 W; G5: 1.75 W; G6: 2.0 W; G7: 2.25 W; G8: 2.5 W; G9: 2.75 W; G10: 3.0 W; G11: 3.25 W; G12: 3.5 W; G13: 3.75 W; and G14: 4.0 W. Samples in the 14 groups (n=10) were conditioned with Clearfil SE Bond and restored with a flowable composite. They were then thermocycled (1000 cycles) and immersed into a 2% methylene blue solution for microleakage analysis. The data were statistically compared (analysis of variance or Spearman correlation tests; $p \leq 0.05$). The lased groups showed significantly greater microleakage indexes, cavity depths, and presence of residual caries than did those of the control group. There was a strong positive correlation between residual caries and microleakage. The results indicate that Er,Cr:YSGG laser irradiation is not a good alternative to the use of burs for root caries removal since it may cause a significant loss of marginal sealing in composite resin restorations.

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INTRODUCTION

Treatment of dental root caries is challenging, especially nowadays, when the elderly population is

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significantly increased worldwide.[1] To improve root caries removal procedures and the longevity of restorations in the elderly population, research is required to develop more comfortable and efficacious clinical procedures.

Root caries may occur when root surfaces become exposed to the oral environment. This exposure can be due to periodontal diseases, mechanical injury, surgical treatment, or a combination of these factors.[2]

The elderly population is at high risk for root caries as a result of health and motor deficiencies that can lead to xerostomia and poor capacity for mouth cleansing. Some clinical situations, such as the presence of deep carious lesions and/or pulpal sensitivity, demand restorative procedures. Research in the elderly population is focused on finding a method with which to remove diseased dental hard tissue without the negative stimuli associated with conventional caries removal techniques.[3]

Currently, the most common method for removing deep root caries lesions is the use of spherical burs in low-speed handpieces.[4] This conventional technique for caries treatment is invasive and has some disadvantages, such as the necessity for local anesthesia during clinical procedures and production of noise and vibration that can be inconvenient for patients. For these reasons, new methods of caries management are being developed, such as laser treatment, particularly using erbium lasers.[5,6]

Since the introduction of the first ruby laser in 1965, many wavelengths have been investigated with regard to their clinical application in dentistry.[7,8] In the past, use of CO_2, Nd:YAG, and ruby lasers for cavity preparation and caries removal produced unsatisfactory results, which included destruction of enamel and dentin as well as increases in pulpal temperature to critical levels.[9] In the late 1980s, desirable results were obtained by using different wavelengths. A study[10] showed that tooth structure could be removed by the Er:YAG wavelength without causing any measurable degree of thermal damage. Furthermore, this study showed that thermal damage to enamel and dentin was minimal when proper settings and an adequate water cooling spray were used.[10]

In the last 10 years, two wavelengths have been developed for clinical use on hard tissues. These include the Er:YAG (2.94 μm) and the erbium, chromium:yttrium-scandium-gallium-garnet (Er,Cr:YSGG) (2.78 μm), which have very similar properties according to many scientific accounts. These two wavelengths constitute the erbium family of lasers. Preliminary studies[5,11] investigating the safety and efficacy of using the Er,Cr:YSGG wavelength found it to be a precise tool for dental hard tissues. Furthermore, it was considered more comfortable for patients than the conventional bur method for caries removal, because less anesthesia or no anesthesia was required during clinical procedures and because the technique presented low noise and no pressure or vibrations on the tooth structure.[5,12] The mechanism of dentin removal by this laser involves a thermomechanical process in which the emission laser light is absorbed by the water within the hydroxyapatite of the dental hard tissue.[13] The water is then heated and evaporated, resulting in high-pressure steam that causes a microexplosion of tooth tissue below the melting point of tooth tissue (approximately 1200°C).[14] The surface irregularities of ablated dentin are comparable to those of the dentin surface after acid etching. This may promote micromechanical interlocking between dental restorative materials and the tooth surface. For this reason, several studies[6,15-19] have aimed to evaluate the adhesion of composites to lased dentin, but the data obtained in these studies are conflicting and inconclusive.

Considering that the Er,Cr:YSGG laser has been advocated especially for preparation of microcavities in light of minimal invasive dentistry[12,20] and given that laser treatment is more comfortable for patients, the efficacy of this caries removal method remains to be clarified. Therefore, the aim of this study was to analyze the efficiency of Er,Cr:YSGG laser irradiation for root caries removal by observation of the macromorphological characteristics of the cavity and microleakage of composite resin restorations.

MATERIALS AND METHODS

Selection of Teeth

Seventy human teeth (molars and premolars) extracted as a result of periodontal disease were used. After cleansing and root planing using a Gracey curette, the teeth were stored in distilled water under refrigeration (4°C). This study was approved by the University of São Paulo School of Dentistry Ethical Committee.

Tooth Preparation

The dental roots were separated from the crowns at the cement-enamel junction using a sectioning machine (Labcut Model 1010; Extec, Enfield, CT,

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Table 1: *Laser Conditions for Experimental Groups*

Groups	Repetition Rate, Hz	Power Output, W	Fluence, J/cm^2
2	20	1	17.85
3	20	1.25	22.31
4	20	1.5	26.78
5	20	1.75	31.24
6	20	2	35.7
7	20	2.25	40.16
8	20	2.5	44.63
9	20	2.75	49.09
10	20	3	53.55
11	20	3.25	58.01
12	20	3.5	62.48
13	20	3.75	66.94
14	20	4	71.4

USA) with a diamond disk (Buehler Ltd, Lake Bluff, IL, USA) at low speed. One hundred and forty dentin blocks (5 × 5 mm) were obtained from the dental roots using the same equipment. The dentin blocks were embedded into acrylic resin (Jet; Classico, São Paulo-SP, Brazil), leaving a 3 × 3-mm root surface–exposed window. Samples were individually placed into 24-well cell culture plates and sterilized by gamma radiation (25 KGY).[21]

For the cariogenic challenge, *Streptococcus mutans* (ATCC 25175) grown repeatedly in sucrose medium was used. The samples in the sterile cell culture plates were coated with 1.5 mL of Brain Heart Infusion broth supplemented with 5% sucrose (BHI-S; Difco, Sparks, MD, USA), inoculated overnight with standardized cultures ($\cong 8.8 \times 10^7$ colony-forming units [CFU]/mL) in the same medium, and incubated for 24 hours at 37°C in an atmosphere containing 10% CO_2. The sterile BHI-S medium was changed at 24-hour intervals during the first four experimental days and then every other day during the next 20 days. All incubations were carried out as previously described.[22,23] After incubation, the root dentin fragments showed macroscopic alterations similar to those of root caries. These samples were then used for experiments.

Experimental Groups

The samples (n=140) were randomly divided into 14 groups (n=10 per group) according to the technique used for caries removal, as follows: group 1 (control): caries removal carried out with a conventional technique using spherical carbide burs in a low-speed handpiece. Groups 2 to 14: caries removal carried out with Er,Cr:YSGG laser irradiation. An Er,Cr:YSGG laser (Waterlase; BioLase Technology Inc, San Clemente, CA, USA) was used at a wavelength of 2.78 μm with a pulse duration of ≅140 μs and a repetition rate of 20 Hz. The average power output of this laser could be varied from 0.0 to 6.0 W. The laser energy was delivered through a fiber-optic system to a sapphire tip (terminal diameter, 600 μm) that was bathed in an adjustable air/water spray. In this study, the power output was set between 1.0 W and 4.0 W at 0.25-W intervals, yielding an energy density ranging from 17.85 to 71.4 J/cm^2, and the air/water spray was adjusted to 55%/65%. Groups were treated as shown in Table 1.

In all groups, caries removal was considered complete when no carious tissue was noted in the cavity walls and at the bottom of the cavity on visual and probe examination. The removal of carious lesions determined the form of the cavity.

Cavity Restoration

The cavities were treated with a self-etch adhesive system (Clearfil SE Bond; batch numbers: primer, 005438; bond, 007234; Kuraray, Osaka, Japan) according to the manufacturer's instructions. The cavities were restored with a flowable composite resin (Palfique Estelite LV; color A3; batch number J244J; Morita Inc, Irvine, CA, USA) in two increments. Each increment of composite resin was light-cured for 30 seconds using an XL 3000 halogen curing light (3M ESPE, St Paul, MN, USA). After 24 hours, the restorations were finished with Sof-Lex disc systems (3M ESPE).

Thermocycling and Microleakage Test

The specimens were thermally cycled using 1000 cycles between water baths at 5°C ± 1°C and 55°C ± 1°C with a one-minute dwell time. The teeth were immersed into 2% methylene blue for four hours and

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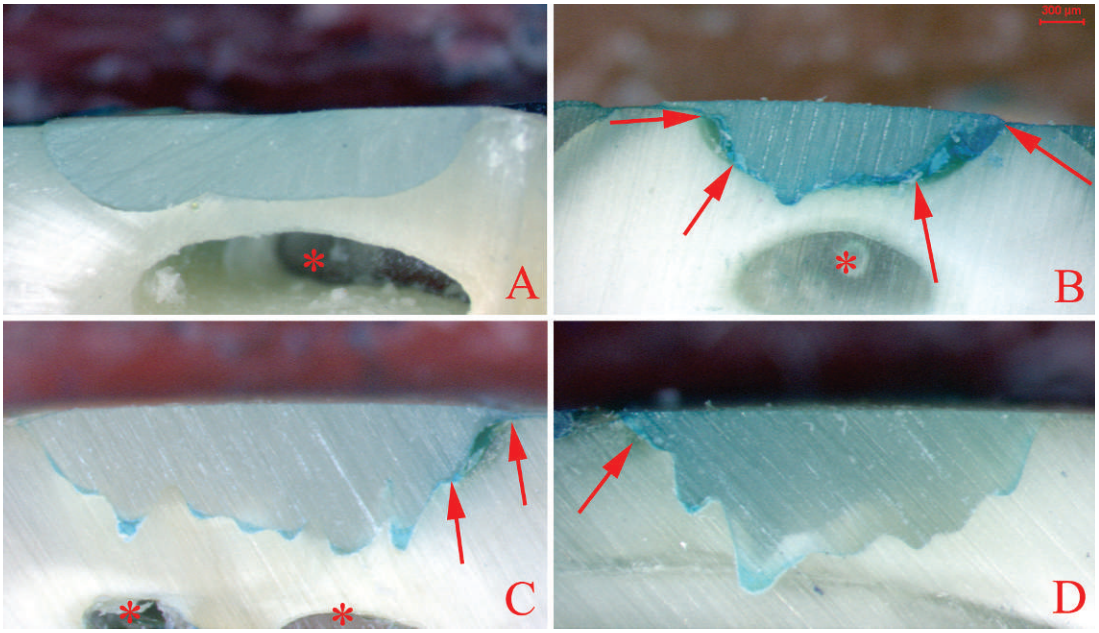

Figure 1. *Representative images of cavities restored after caries removal with a bur (A) and with a laser, using power outputs of 2.0 W (B), 3.0 W (C), and 4.0 W (D). The arrows indicate the presence of residual caries lesions on the cavity walls. It is possible to note that the cavities become more irregular and deeper as the laser power output increases. The symbol (*) identifies the pulp chamber.*

then rinsed with distilled water and air-dried for 10 minutes. Next, the samples were sectioned with a diamond disc (Buehler Ltd) mounted in a sectioning machine (Extec).

The sectioned surfaces were observed using a stereoscope (Stemi SV11; Zeiss, Thornwood, NY, USA) at 40× magnification and photographed with a digital camera (Cybershot 3.3 MPEG Movie EX; model number DSC-S75; Sony, Japan). The digital images obtained were transmitted to a personal computer and analyzed using Axion Vision 3.1 software (Carl Zeiss Vision, Peabody, MA, USA), which performed a standardized assessment of the extent of the tracer agent along the dentin/composite interface and provided quantitative measurements in millimeters. To calculate the percentage of microleakage, the total length of the tooth/restoration interface was measured. Then the length of the interface infiltrated by dye was calculated. These data were used to calculate the infiltration index for each section as the percentage of the interface length showing infiltration, by multiplying the infiltrated interface length by 100 and dividing that value by the total interface length. As three sections per sample were analyzed, it was possible to calculate an average for each sample. The mean dye penetration in the tooth/restoration interface was then calculated for each group. The maximum depth of the cavities, the area of the tooth/restoration interface, and the dye-infiltrated interface area were also measured.

To analyze for the presence of residual caries, the specimens were observed under a stereomicroscope at 40× magnification. The presence of residual caries under the restoration was classified using three scores, as follows: 1, no residual carious lesions; 2, residual lesion in at least one of the lateral walls of the cavity; and 3, residual lesion in the lateral and in the pulpal walls of the cavity.

Statistical Analysis

The data from 10 samples per group were compared by analysis of variance followed by Tukey test. The Spearman correlation test was performed to compare time vs Er,Cr:YSGG laser power outputs and residual caries scores vs infiltration indexes. The level of significance was determined as 5% ($p \leq 0.05$).

RESULTS

Representative photomicrographs of sections of control and experimental samples are presented in Figure 1. The tooth/restoration interfaces of cavities in the control group were regular (Figure 1A). No dye infiltration or residual caries were observed in these samples. When the caries lesions were removed with the Er,Cr:YSGG laser (Figure 1C,D), the tooth/restoration interface was irregular. Different degrees of dye infiltration as well as the presence

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Table 2: *Mean (±Standard Error of the Mean) Values of Maximum Cavity Depths and Mean Areas of Tooth-Restoration Interface of All Experimental Groups (Different Online Small Capital Letters Indicate Statistical Differences Between the Groups)*

Groups	Depth, mm	Interface, mm^2
1	0.84 ± 0.049 A	3.51 ± 0.15 A
2	0.92 ± 0.086 A	4.36 ± 0.14 A
3	0.79 ± 0.031 A	4.17 ± 0.12 A
4	0.81 ± 0.037 A	4.27 ± 0.16 A
5	0.97 ± 0.047 A	5.03 ± 0.14 B
6	0.85 ± 0.034 A	4.58 ± 0.18 B
7	0.92 ± 0.032 A	4.84 ± 0.17 B
8	1.07 ± 0.051 A	4.52 ± 0.38 B
9	1.00 ± 0.033 A	4.64 ± 0.18 B
10	1.27 ± 0.036 B	5.43 ± 0.17 B
11	1.36 ± 0.080 B	5.28 ± 0.19 B
12	1.20 ± 0.053 B	5.17 ± 0.20 B
13	1.29 ± 0.058 B	4.64 ± 0.32 B
14	1.12 ± 0.053 B	4.74 ± 0.18 B

Table 3: *Distribution of the Residual Caries Scores Among the Experimental Groups (1: No Residual Carious Lesions; 2: Residual Lesion in at Least One of the Lateral Walls of the Cavity, and 3: Residual Lesion in the Pulpal Wall of the Cavity)*

Groups	Scores, %			Mode
	1	2	3	
1	100	0	0	1
2	0	50	50	3
3	10	30	60	3
4	0	70	30	2
5	10	80	10	2
6	30	50	20	2
7	30	70	0	2
8	30	60	10	2
9	30	70	0	2
10	20	80	0	2
11	10	70	20	2
12	20	80	0	2
13	10	90	0	2
14	0	100	0	2

of residual caries were observed. In the groups treated with the lowest power, most of the samples showed residual caries in all cavity walls (Figure 1B), whereas in the groups treated with the highest power, residual caries were mainly present in the lateral walls (Figure 1C,D).

The mean values of the maximum depth of the restorations and the area of the tooth/restoration interface of each experimental group are presented in Table 2. The cavities of the control group and of those irradiated with power outputs up to 2.75 W had similar depths. These depths were significantly smaller than those of samples in which higher parameters were used ($p<0.05$). The depths of cavities from samples irradiated from 3 W to 4 W were similar. The tooth/restoration interface areas of samples from groups 1, 2, 3, and 4 (control, 1 W, 1.25 W and 1.5 W, respectively) were similar. These areas were significantly smaller than those of all other groups ($p<0.05$). Samples irradiated with 1.75 W to 4 W presented tooth/restoration interfaces with similar sizes.

Table 3 shows the results of the residual caries examination. All samples in the control group exhibited a score of 1 (ie, no residual caries). All lased groups exhibited residual caries; most of the carious tissue was observed in the lateral wall of the cavities. In groups 2 and 3 (1.0 W and 1.25 W, respectively), residual caries was also found in the

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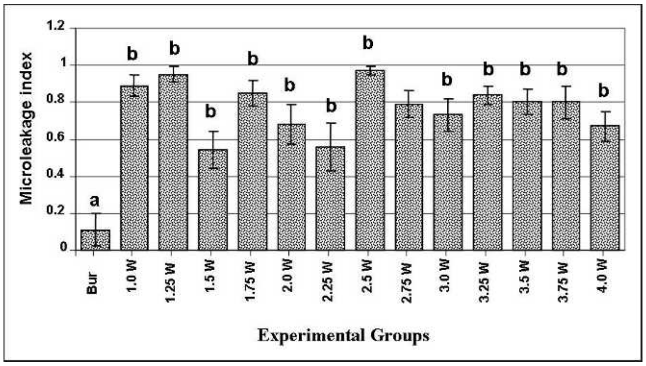

Figure 2. *Mean (±standard error) of the microleakage index in the different experimental groups. Different letters represent statistically significant differences.*

pulpal wall. For microleakage analysis of the restorations, an infiltration index was used. This index was calculated by dividing the area of the dye-infiltrated interface by the total tooth/restoration interface. The mean microleakage index of each group is represented in Figure 2. The infiltration indexes of all lased groups were similar and significantly higher than that of the control group ($p<0.05$).

To verify whether the presence of residual caries had an influence on the microleakage index, the Spearman correlation test was performed. There was a strong positive correlation between residual caries and the degree of infiltration (r=0.35; $p=0.0001$).

DISCUSSION

The methods used for dental caries removal can create dental substrates that have different interactions with restorative materials. The longevity of dental restoration directly depends on these interactions. The presence of a smear layer, irregularities on the cavity walls and margins, the orientation and diameter of the dentinal tubules, or even the presence of remaining caries can affect the success of the adhesive restoration that is performed after caries treatment. For this reason, a comparison between the conventional dental caries removal method using burs at low speed and laser treatment was performed in the current study. Characteristics related to caries removal and tooth restoration were analyzed, such as the depth of the cavities, the adhesive interface, the presence of residual caries, and the marginal seal (microleakage index). The marginal seal of composite resin restorations after root caries removal using the Er,Cr:YSGG laser method was worse than that obtained after caries lesion removal facilitated using a bur. In fact, microleakage indexes, as well as the presence of residual caries, were significantly higher in the lased groups.

The microbiologic artificial caries system was used in this study to produce lesions as similar as possible to those that develop naturally. This model utilizes a specific bacterial culture to induce demineralization as well as protein denaturation of the tooth tissues. Moreover, although the *in vitro* chemical model for caries induction allows better experiment control, this method does not reproduce the *in vivo* situation in such a refined manner as the bacterial model.[24] *Mutans* streptococci were chosen for the cariogenic challenge because they are the major microorganisms involved in development of caries lesions.[25]

The induction of *in vitro* caries using the biological method created dentin lesions that were very similar to caries lesions in both clinical and microscopic aspects. This carious substrate is appropriate for studying caries removal because it offers a substrate similar to that present under *in vivo* conditions.[24]

The main purpose for developing the use of lasers in dentistry was to find a new method for caries removal and cavity preparation that did not result in the typical discomforts associated with the conventional method of caries treatment, such as noise, pressure, vibrations, heating of the tooth structure, and the requirement for local anesthesia. Despite the advantages of the laser treatment previously stated, one factor that could be considered a disadvantage of laser treatment is the time required for caries removal. According to previous research,[26] the conventional method for caries removal is faster than Er,Cr:YSGG treatment. However, in our opinion, considering the patient's comfort (absence of noise and vibration and, sometimes, no requirement for local anesthesia), the longer clinical time required for laser use becomes irrelevant.

In the present study, the removal of carious lesions determined the cavity form. A previous study[26] has shown that the cavity morphology as well as the dentin substrate topography obtained with burs and the Er,Cr:YSGG laser are different. With burs, the margins and depth of the cavities obtained are smoother and smaller, respectively, than those of laser-obtained cavities, especially when parameters higher than 2.75 W are used. The results of that study indicated that the dentin was coated with smear layer when caries lesions were removed with burs and the Er,Cr:YSGG laser with parameters lower than 2.0 W, whereas laser treatment with higher parameters was able to remove carious tissue,

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leaving the dentinal tubules open.[26] Hypothetically, this morphological characteristic makes a substrate more favorable for adhesion. However, in the present study, the substrate obtained by laser treatment led to poorer adhesion, as revealed by a significant increase in the microleakage index.

This research used extracted teeth. It is known that the dentin of a vital tooth has some different characteristics from the dentin samples used here; for example, the presence of odontoblastic processes and fluids. There are no reports comparing the effectiveness of the laser ablation of dental hard tissues of vital and nonvital teeth. However, we believe that there is no significant difference in that case, since all the irradiation was carried out using water cooling spray, and, thus, the presence of the dentin fluid becomes insignificant if we take into consideration the quantity of water used during irradiation. Furthermore, to avoid carbonization and other side effects, laser cavity preparation must be done with proper water cooling.[27]

The higher microleakage indexes observed in the laser groups could be due to the presence of residual caries as well as the inability of the Er,Cr:YSGG laser to remove hydroxyapatite crystals without causing damage to the collagen network. Both situations could harm hybrid layer formation. Although these aspects have not yet been described for the Er,Cr:YSGG laser, it has been reported[28] that the Er:YAG laser severely alters the dentin subsurface and causes collagen fibrils to lose their cross-banding and fuse together, thereby eliminating interfibrillar spaces and impairing hybridization.

The Er,Cr:YSGG laser and the Er:YAG laser have almost the same wavelength; therefore, they have similar interactions with hard dental tissue. Therefore, the effect of Er,Cr:YSGG on the dental substrate may damage collagen. In fact, a previous study[17] showed gaps between dentin irradiated with an Er,Cr:YSGG laser and the adhesive interface, indicating alteration in collagen. Morphological alterations produced by Er,Cr:YSGG laser irradiation adversely influence the bonding effectiveness of adhesives to dentin.[19]

One factor closely related to failures in marginal sealing of the laser-treated samples was the fact that the equipment used was not able to completely remove the carious tissue in the lateral walls of the cavity. According to our data, there was a strong positive correlation between the infiltration index and the amount of residual caries under the restorations. These findings concur with those found by other authors,[29] who have reported that the Er:YAG laser was not able to remove all infected carious tissue, with these residual caries noted only at the microscopic level. The current results also show the importance of working with carious dentin substrates rather than healthy dentin for *in vitro* analysis of the marginal seal quality of restorations.

In the present study the cavities were treated with a self-etch adhesive system prior to the placement of the composite resin. According to clinical results obtained in the past,[30-32] we believe that the two-step self-adhesive systems are effective, which justifies their use in the present study. Unlike etch-and-rinse adhesives, self-etch adhesives do not involve a separate etching step, as they contain acidic monomers that simultaneously 'condition' and 'prime' the dental substrate, rendering the technique less sensitive and faster. The reduction in clinical steps is especially important in the case of laser preparations, which require more time to produce than is required of the conventional method. Thus, if the clinical time during laser treatment is reduced, it will make this treatment more comfortable to the patients. Another clinical advantage of self-etch adhesives is the lower incidence of postoperative sensitivity experienced by patients when compared to the cases in which etch-and-rinse adhesives were used.[33] This is attributed to their less aggressive and more superficial interaction with dentin, leaving tubules largely obstructed with smear.[34] Additionally, studies[34,35] have shown that both two-step self-etch and etch-and-rinse techniques have performed successfully in laboratory as well as in clinical research.

The material used to fill the cavities was a flowable resin composite. In fact, previous studies[23,36] have shown that cavity restoration with resin-modified glass ionomer cement (GIC) leads to an efficient adhesion to the dentinal surface for cavities prepared after root caries removal with erbium lasers. These studies indicate that this laser promoted a modification of the dentin substrate by increasing the quantity of calcium, which in turn improved adhesion to the GIC.[23,36] However, although GICs have good adhesion in cavities prepared with erbium, it is important to know if other restorative materials, such as flowable composites, have the same success with GICs. According to past studies,[37-39] flowable composites present mechanical properties similar to those of microhybrid composites: low shrinkage stress, adequate marginal sealing, and high bond strength. Nevertheless, those characteristics were not able to prevent the micro-

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leakage of the restorations placed in cavities prepared by the Er,Cr:YSGG laser.

CONCLUSIONS

In conclusion, the removal of root carious tissue using an Er,Cr:YSGG laser with power outputs between 1 W and 4 W creates a dentin substrate unfavorable for promoting marginal sealing. To take advantage of the positive characteristics of Er,Cr:YSGG laser irradiation, especially the added comfort for dentists and their patients, new studies should be performed with equipment allowing more flexibility in the determination of parameters, as well as the use of other restorative materials; this would confirm that irradiation is an alternative method for removal of dental root caries. These studies would help to achieve restorations with both good esthetic results and longevity, improving the life quality of patients through the maintenance of oral health, particularly in the elderly population.

Conflict of Interest

The authors of this article certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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