

# The influence of erbium:yttrium–aluminum–garnet laser ablation with variable pulse width on morphology and microleakage of composite restorations

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**Abstract** The objective of this study was to evaluate the influence of various pulse widths with different energy parameters of erbium:yttrium–aluminum–garnet (Er:YAG) laser (2.94  $\mu\text{m}$ ) on the morphology and microleakage of cavities restored with composite resin. Identically sized class V cavities were prepared on the buccal surfaces of 54 bovine teeth by high-speed drill ( $n=6$ , control, group 1) and prepared by Er:YAG laser (Fidelis 320A, Fotona, Slovenia) with irradiation parameters of 350 mJ/ 4 Hz or 400 mJ/2 Hz and pulse width: group 2, very short pulse (VSP); group 3, short pulse (SP); group 4, long pulse (LP); group 5, very

long pulse (VLP). All cavities were filled with composite resin (Z-250-3 M), stored at 37°C in distilled water, polished after 24 h, and thermally stressed (700 cycles/5–55°C). The teeth were impermeabilized, immersed in 50% silver nitrate solution for 8 h, sectioned longitudinally, and exposed to Photoflood light for 10 min to reveal the stain. The leakage was evaluated under stereomicroscope by three different examiners, in a double-blind fashion, and scored (0–3). The results were analyzed by Kruskal–Wallis test ( $P>0.05$ ) and showed that there was no significant differences between the groups tested. Under scanning electron microscopy (SEM) the morphology of the cavities prepared by laser showed irregular enamel margins and dentin internal walls, and a more conservative pattern than that of conventional cavities. The different power settings and pulse widths of Er:YAG laser in cavity preparation had no influence on microleakage of composite resin restorations.

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## Introduction

The erbium:yttrium–aluminum–garnet (Er:YAG) laser wavelength of 2.94  $\mu\text{m}$  is highly absorbed in both water and hydroxyapatite and has great applicability in dental hard tissues [1, 2]. Several previous in vitro and clinical studies have shown the efficiency and applicability of Er:YAG laser on caries removal, enamel and dentin etching and cavity preparation [3–5].

Since 1989, when Hibst and Keller [6] demonstrated the efficacy of Er:YAG laser irradiation on ablation of enamel

and dentin, the number of investigations using this wavelength in dentistry has been steadily increasing. Most of the papers described in vitro studies of cavity preparation, measurement of temperature increase, microscopic analysis of morphology, cooling effects, evaluation of efficient and safe power settings, microleakage, and bond strength tests.

The morphological analysis showed that cavities prepared by Er:YAG laser had irregular cavosurfaces and floors. The laser cannot prepare box-shaped cavities with sharp lines and definite angles, restricting it to removal of carious tissue, and, therefore, to preparation of cavities of conservative patterns and, typically, restorations of composite resin or glass ionomer cement [4, 7–9].

The dental cavity prepared by Er:YAG laser systems may be considered to be as safe as the conventional high-speed drill [8, 10–12]. Histopathological evaluations demonstrated no difference or less pulpal inflammatory response after laser treatment when compared with conventional drill [13].

Since 1997, the Food and Drug Administration (FDA) has cleared the clinical use of Er:YAG laser for cavity preparation in the United States of America and recently cleared this wavelength for use on dental hard tissues in children [13, 14].

The morphological analysis by scanning electron microscopy (SEM) of enamel and dentin irradiated by Er:YAG laser demonstrated that the enamel had a micro-retentive pattern and the dentin had no formation of a smear layer with opened dentinal tubules [2, 9, 15–18]. Staninec et al. [15] achieved similar values of shear bond strength with Er:YAG conditioning in comparison with acid etch. On the other hand, previous studies [19, 20] on enamel and dentin substrates showed that Er:YAG laser associated with acid etching or self-etching primers produced bond strength values comparable to those achieved with acid etching or self-etching primers. It has been demonstrated that the use of Er:YAG laser for cavity preparation and surface treatment negatively influenced the sealing of dentin margins [21]. Shigetani et al. [22] compared the marginal seal of enamel and dentin between cavities prepared by Er:YAG laser irradiation and drill and found no significant differences. This suggested that Er:YAG laser irradiation does not eliminate the need for phosphoric acid or self-etching primers because the bonding agents and composite resins do not penetrate deeply enough and bond to non-etched lased surfaces.

The cavities made by Er:YAG laser following phosphoric acid etching showed enhanced marginal integrity and achieved microleakage values similar to those of conventional cavities created by air turbine following phosphoric acid etching. These findings were confirmed in several studies [7, 22–28]. The main factor influencing the

longevity of dental restorations is microleakage at the tooth–restoration interface; therefore, microleakage has been the focus of attention when the performance of restorative materials has been appraised [29].

The purpose of this study was to evaluate the influence of various pulse widths with different energy parameters of Er:YAG laser on morphology by scanning electron microscopy and microleakage using the dye penetration method of cavity preparation restored with composite resin.

## Materials and methods

Fifty-four bovine upper incisors, stored in 0.9% sodium chloride (NaCl) solution to prevent dehydration, were used in this in vitro study. Class V cavities with an approximate depth of 2 mm, occluso-gingival length of 2 mm and mesio-distal width of 4 mm, with cavosurface margins placed in enamel, were formed on the buccal enamel surface. In six bovine teeth six cavities were prepared with a conventional, water–air cooled, high-speed-drill (KaVo, Brazil) (group 1), using a diamond bur no. 1090 (KG-Sorensen, Brazil). The laser-prepared cavities were fashioned with an Er:YAG laser (Fidelis 320A, Fotona, Slovenia) with an emission wavelength 2.94  $\mu\text{m}$ , energy per pulse of 40–1,000 mJ, pulse repetition rate of 2–50 Hz, and a low-power visible aiming beam (diode, 650 nm). In 48 bovine teeth, the cavities were prepared with an Er:YAG laser, focused and aligned perpendicularly 12 mm from the buccal enamel surfaces of the teeth, with air–water spray cooling (25 ml/min); delivered via an articulated arm that was connected to a straight handpiece (RO2). Various pulse widths were used: very short pulse (VSP; 75–100  $\mu\text{s}$ ; group 2); short pulse (SP; 250  $\mu\text{s}$ ; group 3); long pulse (LP; 450–550  $\mu\text{s}$ ; group 4); very long pulse (VLP; 750–950  $\mu\text{s}$ ; group 5). One cavity was prepared on the buccal surface of each tooth, with energy parameters of 400 mJ/2 Hz and 350 mJ/4 Hz. There were six cavities in each experimental laser group and a total of 48 laser cavities (Table 1).

The entire class V cavities were etched with 35% phosphoric acid for 15 s, treated with two consecutive layers of Single Bond adhesive (3M, St. Paul, MN, USA) and light cured by visible light (XL3000, 3M, Brazil) for 10 s. The cavities were restored with composite resin Z-250 (3M, St. Paul, MN, USA) color A-2, added in approximately 1 mm increments. Each increment was polymerized for 20 s with visible light (XL3000, 3M, Brazil). After that, the restorations were stored in distilled water for 48 h at 37°C, then the specimens were polished with Sof-Lex disks (3M, St. Paul, MN, USA). To age the restorations, we thermally stressed the specimens (Nova Ética, Vargem Grande Paulista, Brazil) for a total of 700 cycles, at temperatures of 5°C and 55°C, with a dwell time of 1 min

**Table 1** Methods of cavity preparation in the different groups

Group	Preparation method	Pulse width	
1	High speed- drill (control) ( <i>n</i> =6)	–	–
2	Er:YAG laser	400 mJ/2 Hz	350 mJ/4 Hz
3		VSP ( <i>n</i> =6)	VSP ( <i>n</i> =6)
4		SP ( <i>n</i> =6)	SP ( <i>n</i> =6)
5		LP ( <i>n</i> =6)	LP ( <i>n</i> =6)
		VLP ( <i>n</i> =6)	VLP ( <i>n</i> =6)

in each bath and a 3 s transfer time between baths. Afterwards, the specimens were made impermeable with nail polish layered over the entire surface, except for a 2 mm area around the restoration margin. The apices were sealed with cyanoacrylate. The teeth were immersed in a 50% silver nitrate aqueous solution for 8 h in the dark and then washed in running water for 10 min.

The teeth were embedded in resin, chemically activated (Redefibra, Brazil), and a 1 mm-thick longitudinal section was cut in a buccolingual direction through the center of the restoration with a modified water-cooled, low-speed diamond saw (Labcut 1010 Extec, Enfield, CT, USA). The samples were exposed to a Photoflood light (G.E., Rio de Janeiro, Brazil) of 250 W, for 10 minutes, to reveal the silver nitrate leakage at tooth–restoration interface. The degree of microleakage, indicated by the dye penetration at the tooth–restoration interface, was evaluated under a stereoscope (Olympus, SZ/40, Tokyo, Japan) at  $\times 4$  magnification by three qualified evaluators, in a double-blind fashion. Three sections in each restoration were analyzed, based on a scale of scores [30] as shown in Table 2, and the occlusal and cervical edges of each restoration were evaluated.

After examination under the stereoscope, three representative samples from each group were chosen for morphological evaluation by scanning electron microscopy. All specimens were dehydrated in a graded series of aqueous ethanol (25%, 50%, 75%, 90% and 100%). The time used for each alcohol grade was 20 min, 20 min, 20 min, 30 min and 1 h, respectively. The specimens were gold coated with a sputter coater SCD-050 (Bal-Tec, Liechtenstein). SEM images were obtained with a JXA-6400 scanning electron microscope (JEOL, Tokyo, Japan) at 20 kV. The magnifications ranged from  $\times 30$  to  $\times 4,000$ .

**Table 2** Criteria for microleakage scores at the tooth–restoration interface

Score	Criterion
0	No microleakage
1	Microleakage observed only at the cavity wall of enamel
2	Microleakage observed at the cavity wall of dentin but not on the cavity floor
3	Microleakage observed on the cavity floor

## Results

### Evaluation of microleakage by stereoscopy

The microleakage data from the 18 stereoscopic observations conducted for each experimental group (Table 3) were subjected to statistical analysis by the Kruskal–Wallis test with a 5% level of confidence. The results showed that the three double-blind evaluators were in agreement and that there was no significant difference between occlusal and cervical margins of the cavities prepared by laser ( $P > 0.05$ ). There was no significant difference between occlusal and cervical margins of the cavities prepared by high-speed drill ( $P > 0.05$ ). The cavities prepared by Er:YAG laser had no significant differences from those prepared by high-speed drill ( $P > 0.05$ ). There was no difference between the cavities prepared by laser of different pulse widths ( $P > 0.05$ ) and different energy parameters ( $P > 0.05$ ). All groups demonstrated a predominance of score 0 (no leakage) (Figs. 1 and 2). The score 1 (minimal leakage) (Fig. 1) showed up more in the LP, VLP and control (high-speed drill) groups than in the VSP and SP groups; however, there were no significant differences between them ( $P > 0.05$ ). Only one cavity showed a score of 2 (moderate leakage), and no cavity demonstrated a score of 3 (severe leakage) (Tables 2 and 3).

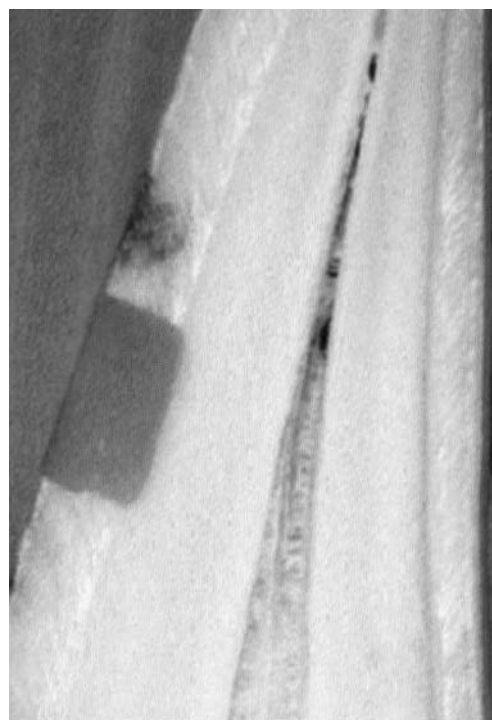
### Morphological analysis by SEM

The cavities created by Er:YAG laser showed differences under SEM not only in the shape of the cavity but also in the quality of the internal wall surface, in comparison with the cavities made by high-speed drill (Figs. 3, 4). The cavities formed with the laser using different pulse widths

**Table 3** Numbers of repeated microleakage scores in the different experimental groups

Preparation method	Occlusal margin				Cervical margin				
	Scores				Scores				
	0	1	2	3	0	1	2	3	
400 mJ/2 Hz	VSP	18	–	–	–	18	–	–	–
	SP	17	1	–	–	17	1	–	–
	LP	15	3	–	–	14	4	–	–
	VLP	14	4	–	–	16	2	–	–
350 mJ/4 Hz	VSP	18	–	–	–	18	–	–	–
	SP	17	1	–	–	18	–	–	–
	LP	13	4	1	–	13	5	–	–
	VLP	14	4	–	–	15	3	–	–
High-speed drill		12	6	–	–	15	3	–	–

demonstrated rough enamel margins (Fig. 4b), irregular and rugged walls (Fig. 4), and a conical shape (Fig. 4a) with a small diameter and deep in comparison with the shape of the cavities made with the high-speed drill, which showed enamel margins sharply determined in the SEM morphological analysis (Fig. 3b), flat and smooth internal walls,

**Fig. 1** Stereoscopy photograph for a score of 0 observed on the cervical margin and a score of 1 observed on the occlusal margin in group 1 (Er:YAG laser, VSP, 350 mJ/4 Hz).  $\times 4$ **Fig. 2** Stereoscopy photograph for a score of 0 observed on the occlusal and cervical margins in group 5 (control, high speed drill).  $\times 4$ 

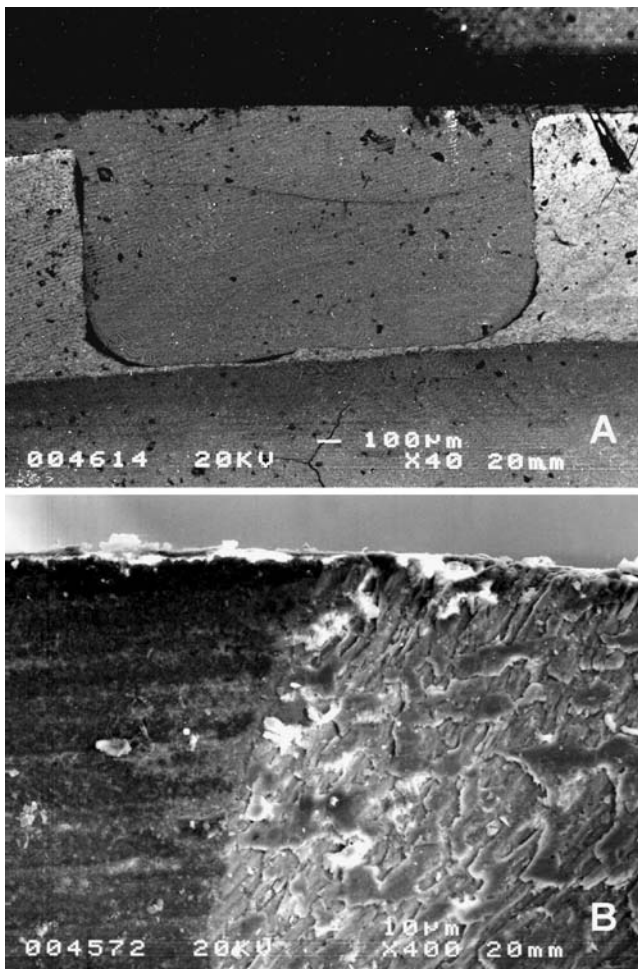
and a geometrically well-defined shape (Fig. 3), wider and shallower than the laser-prepared cavities.

The microleakage and penetration of silver nitrate at the tooth–restoration interface were demonstrated by SEM with silver globules along the bonding–composite resin interface or into dentinal tubules (Fig. 5).

## Discussion

Studies have been performed to minimize or eliminate microleakage related to gaps or cracks in the margins of composite restorations. Many factors, such as fit and attachment of composite resin, difference in coefficient of thermal expansion, forces of polymerization contraction, adhesive system used, size and shape of cavities and margins, and location of margins and occlusal loads, affect the clinical durability of restorations.

In this *in vitro* study, using dye penetration we investigated the microleakage after resin filling class V cavities prepared by Er:YAG laser with different pulse widths or with conventional high-speed drill. The morphology of the cavities was examined by SEM. The results showed that there was no significant difference in microleakage between occlusal and cervical margins of the cavities, between cavities prepared by laser and those prepared by high-speed drill, between the different pulse widths used in cavity preparation by laser, or the different



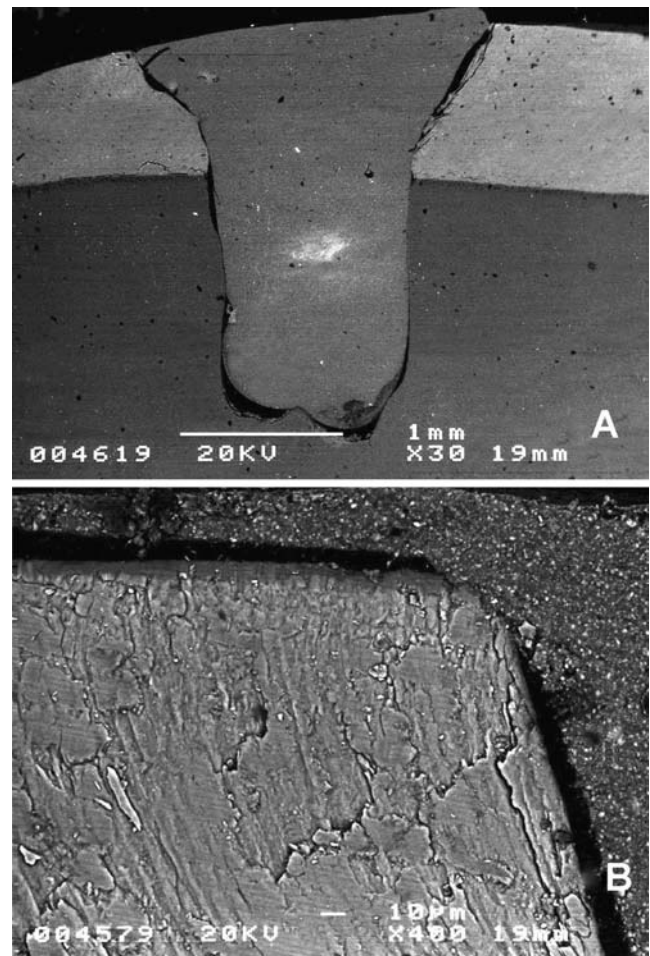
**Fig. 3** SEM photographs of the cavity prepared by high-speed drill (group 1, control) demonstrates (a) flat and smooth cavity walls and floor and geometric shape of the cavity.  $\times 40$ . The bar represents 100  $\mu\text{m}$ . b Sharply defined and regular enamel cavosurface margin.  $\times 400$ . The bar represents 10  $\mu\text{m}$

energy parameters used in the laser-prepared cavities ( $P > 0.05$ ). The score of 0 was predominant in all groups, showing an absence of marginal leakage and efficiency of the laser system, pulse widths and parameters used in this study; the sign of minimal leakage (score 1) appeared in all groups, mainly in the cavities prepared by VLP and LP laser or by high-speed drill.

Cavities created by Er:YAG laser and conventional drill, both associated with phosphoric acid etching, demonstrated similar results and less microleakage than cavities prepared by Er:YAG laser and not etched with phosphoric acid [7, 23, 25]. However, Wright et al. [31] demonstrated no statistical difference in microleakage between cavities prepared and etched by Er:YAG laser, those prepared by high-speed drill and etched with phosphoric acid, and those prepared by high-speed drill and with only the cavosurface enamel etched by Er:YAG laser irradiation. Khan et al. [24] evaluated microleakage in cavity preparations and demon-

strated no significant difference between cavities prepared by Er:YAG laser and those prepared by air turbine; however, the cavities filled with composite resin or glass ionomer showed, under SEM, significant minimal or moderate leakage and good adaptation in comparison with the cavities filled with amalgam, which, under SEM, showed severe leakage and slightly poorer adaptation.

In another study, Niu and colleagues [26] demonstrated by SEM that there were no differences in microleakage scores and measurement of the gaps between cavities prepared by Er:YAG laser and those prepared by air turbine. Corona et al. [27] showed that class V cavities fashioned by high-speed drill, aluminum oxide air abrasion or Er:YAG laser, all following acid etching, demonstrated similar microleakage patterns at the enamel margins. Araujo and co-workers [30] evaluated by SEM the microleakage and nanoleakage in restorations prepared with Er:YAG laser and conventionally, and demonstrated that



**Fig. 4** SEM photograph of the cavity prepared by Er:YAG laser (group 5, very long pulse, 350 mJ/4 Hz) demonstrates (a) irregular cavity walls and floor and conical shape of cavity.  $\times 30$ . The bar represents 1 mm. b Irregular and rough enamel cavosurface margin with scale-like aspect.  $\times 400$ . The bar represents 10  $\mu\text{m}$

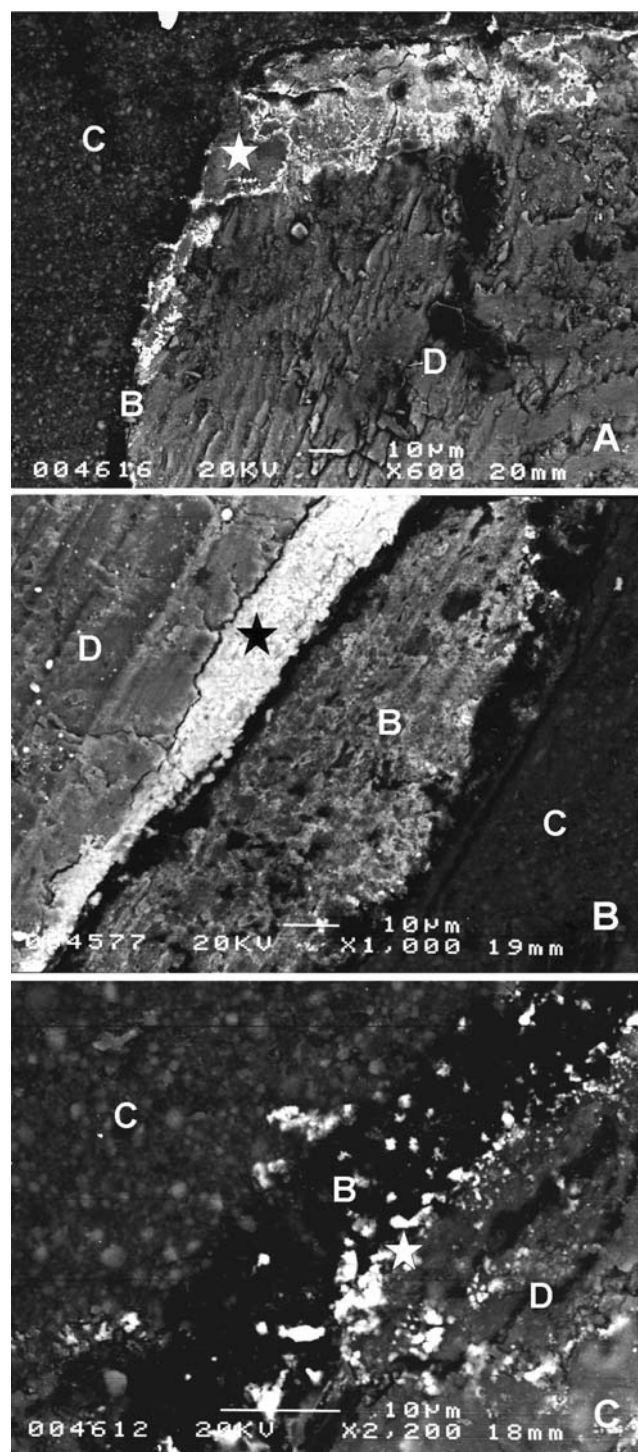
**Fig. 5** SEM images of the interface between the composite resin (C) and cavity walls (a) prepared by high-speed drill (group 1, control) demonstrate good adaptation, and the silver globules (asterisk) penetrate into the interface between the dentin (D) and the bonding agent (B).  $\times 600$ . The bar represents 10  $\mu\text{m}$ . **b** Prepared by Er:YAG laser (group 2, very short pulse; 400 mJ/2 Hz). Image shows the silver globules (asterisk) that have penetrated the interface between the dentin (D) and the bonding agent (B).  $\times 1,000$ . The bar represents 10  $\mu\text{m}$ . **c** Image of a cavity prepared by Er:YAG laser (group 5, very long pulse, 350 mJ/4 Hz) shows higher magnification of the silver globules (asterisk) that have penetrated the dentin (D)–bonding agent (B) interface and the composite resin (C).  $\times 2,200$ . The bar represents 10  $\mu\text{m}$

cavities prepared by Er:YAG laser, following acid etching and treated with neodymium:yttrium–aluminum–garnet (Nd:YAG) laser after polymerization of Single Bond adhesive, showed less microleakage and nanoleakage. After the evaluation of the microleakage level in primary teeth, Kohara et al. [5] showed that there was significantly less microleakage in cavities prepared by laser and filled with composite resin than in those prepared by high-speed drill. Otherwise, Aranha and colleagues [28] demonstrated similar microleakage scores for cavities created by high-speed drill and Er:YAG laser but differences among the adhesives tested.

Those previous studies showed results in agreement with our results, suggesting that Er:YAG laser followed by acid etching promotes results similar to those in conventionally prepared cavities; the Er:YAG laser is useful for cavity preparation, although it is relevant that the characteristics of the adhesive system or composite resin used in this study could have reduced microleakage in the laser-prepared cavities.

Our study showed no significant difference between occlusal and cervical margins of cavities, prepared by laser and high-speed drill ( $P > 0.05$ ). These results are in accordance with those of previous studies [26–28], but other studies have reported higher microleakage scores in the cervical margin than in the occlusal margin [7, 23, 25]. The morphological analysis of cavity preparation by SEM confirmed the results of the observation of microleakage by stereoscopy (Fig. 1 and 2). The adaptation between the composite resin and the internal walls of the cavities demonstrated no difference between the cavities prepared by Er:YAG laser and those prepared by high-speed drill (Figs. 3a, 4a).

The cavities prepared by laser showed irregular and rugged cavity walls, and especially on the cavity floors, observed by stereoscopy and SEM (Fig. 4), it was very hard to flatten the cavity floor by laser, as demonstrated in previous studies [3, 7, 24, 26, 31, 32], but there was no difficulty in filling the cavity with restorative material. The enamel margin produced during Er:YAG laser preparation appeared rough (Fig. 4b) in comparison with that produced



by conventional high-speed drill (Fig. 3b), creating an increase of surface area to bonding [17, 20, 31]. The laser irradiation delivered by waveguide produced a cavity that had a small diameter and was deep; therefore, the volume of hard tissue that was removed was smaller than that removed from conventionally prepared cavities [32]. Under SEM, the cavities prepared by high-speed drill showed smoother relief, with flat internal walls, more specific at the

cavity floors (Fig. 3a), and a sharp enamel margin (Fig. 3b). The conventional high-speed drill produces a wider and shallower cavity, with a well-defined geometric shape and sharp internal angles [3, 7, 24, 26, 32].

The main difficulty in using the Er:YAG laser is the control of irradiation in the desired direction and to the desired depth—the operator has to create and develop a new ability. The ablation effect does not directly depend only on laser energy, and the operator has to consider the pulse width and repetition rate. For effective ablation, there is an optimum energy and number of pulses, and it is not possible to increase the laser energy and repetition rate because this results in temperature increase [8, 10, 11].

The speed of cavity preparation by Er:YAG laser is slower than that by conventional drill. The increase of laser energy and repetition rate causes discomfort and pain in the patients, increases the temperature, and could lead to thermal damage of the pulp and hard tissues; for this reason the increase in laser ablation speed is limited.

In this study we could verify that using the same energy and repetition rate resulted in longer preparation times of cavities when VSP and SP laser were used, and the cavities showed a more defined shape than those prepared with LP and VLP laser. Further studies are required to evaluate ablation efficiency, thermal effects, and patients' acceptance and pain when long and very long pulses with lower energy parameters are used.

The parameters used in this study were safety values for irradiation of dental hard tissues, in accordance with previous studies performed by Gouw-Soares et al. [10] and Raucci-Neto et al. [11], which demonstrated a pulpal temperature rise less than 3°C, well below the safe temperature of 5.5°C that Zach and Cohen [33] recommended. This temperature rise would not cause irreversible histologic damage to the pulpal tissues.

Previous studies that evaluated the thermal effects of Er:YAG laser in animal and in vitro experiments have revealed that thermal irritation of the pulp can be prevented if pulse energies of 100–400 mJ and pulse repetition rates of 1–4 Hz with water spray are used [8, 10, 11]. Temperature increases in clinical procedures are expected to be lower than those in in vitro studies, due to the presence of pulpal tissue. Husein et al. [34] irradiated dentin with Er:YAG laser (Fidelis, Fotona) with different energy parameters (100–600 mJ), repetition rates (5 Hz, 10 Hz, 20 Hz, 30 Hz, 40 Hz, 50 Hz) and pulse widths (VSP, SP, LP, VLP). All parameters promoted an absence of smear layer, opened dentinal tubules, and more ablation of intertubular dentin than of peritubular dentin. Scanning electron micrographs confirmed that the reduced parameters produced projections around the dentinal tubules. The increase in energy/repetition rate/pulse width promoted more micro-irregularities in the intertubular dentin, and the higher parameters left the morphology less distinct and uniform.

The characteristics of the ablated tissue have been considered to be important factors for adhesion, due to the irregular and micro-retentive morphological pattern of the surface with open dentinal tubules and free of smear layer, which differs from the morphological features obtained by conventional techniques of cavity preparation [5, 16, 17]. This pattern has been described as favorable to adhesive procedures [20], but Er:YAG laser can lead to a chemical and structural modification of the tooth surface [35–37]. Camerlingo et al. [36] affirmed that very long pulses (1,000  $\mu$ s) resulted in a dentin surface similar to that obtained with a conventional drill and that a decrease in the pulse time increased laser ablation but produced modifications in dentinal collagen. Dispersive Raman spectroscopy was selected to evaluate Er:YAG lased dentin of specimens treated with 250 mJ and short pulse (300  $\mu$ s), and it was observed that the peak related to collagen showed a decrease in intensity [35]. On the other hand, when X-ray diffractometry and Fourier transformed infrared spectroscopy were used to investigate mineral and organic content, Er:YAG lased dentin demonstrated no significant changes in structure and composition [37].

According to Délme et al. [38], cavities cut by laser do not provide precise and defined cavity outlines, whereas a high-speed bur provides well-defined walls and angles. Another factor that has to be considered is the evaporation of moisture from the lased surfaces of the dentin after irradiation and the consequent dehydration. It has been demonstrated that increased frequency produces higher mass loss and more melted areas.

Clinical trials have demonstrated that Er:YAG laser is a safe and effective alternative for caries removal and cavity preparation, with acceptance and comfort to the patients and a pulpal response and histological effects similar to those of conventional high-speed drill [3, 4, 8, 13]. The Er:YAG laser is useful for cavity preparation with the energy parameters, pulse width, delivering laser system, cavity shape and filling materials used in this study. The interaction between phosphoric acid and different resin monomers of bonding agents with dental hard tissues treated by Er:YAG laser irradiation has been the object of different studies, which showed that the interaction mechanism is not well defined and that further investigations focusing on laser energy absorption and interaction with hydroxyapatite, collagen fibers and water of hard tissues are needed, which assess new perspectives that explain the physical and chemical interaction of bonding agents and dental tissues.

## Conclusion and summary

Previous studies have shown that Er:YAG laser (2.94  $\mu$ m) is highly absorbed in both water and hydroxyapatite and has great applicability to cavity preparation.

The degree of marginal microleakage in composite restorations prepared by Er: YAG laser with varying pulse widths and different energy parameters and by conventional high-speed drill was investigated by dye penetration and morphological evaluation by SEM

According to the results obtained in this experiment and using dye penetration, we concluded that laser irradiation parameters and pulse width used for cavity preparation with Er:YAG have no influence on microleakage.

The SEM morphology analysis of cavities created by laser showed irregular enamel margins and dentinal internal walls, with a more conservative pattern than that of conventionally prepared cavities.

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