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Morphological, optical, and elemental analysis of dental enamel after debonding laminate veneer with Er,Cr:YSGG laser: A pilot study

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Abstract

Laminate veneer removal is becoming a routine procedure at the dental clinic and the use of laser can facilitate its removal. This work aimed to evaluate the morphological, elemental, and optical changes in the remaining enamel after veneer removal using Er,Cr:YSGG laser. Forty-four enamel slabs were prepared and randomly distributed into nine experimental groups, for bonding using lithium disilicate laminates with three different luting agents (Variolink Veneer, RelyX U200, and RelyX Veneer). Then each agent was debonded using Er,Cr:YSGG laser (2.78 μm) using two different protocols:3.5 W, 48.14 J/cm^2, 20 Hz non-contact and 3.0 W, 48.14 J/cm^2, 20 Hz non-contact. The morphological, optical, and elemental analysis of enamel was performed before cementation and after laser debonding, using scanning electron microscopy (SEM), optical coherence tomography (OCT), and energy-dispersive X-ray spectroscopy (EDS). The level of statistical significance adopted was 5%. The EDS analysis of enamel after debonding revealed a significant increase in silane and carbon, as well as a decrease in calcium and phosphate contents. Analysis showed the presence of residual cement in most experimental groups but the morphological analysis showed alteration of the enamel's prisms only in the groups that used RelyX Veneer and Variolink Veneer cements. There was no evidence of deleterious morphological changes resulting from irradiation. However, an increase in the optical attenuation coefficient by the OCT was observed due to the presence of the remaining cement. It can be concluded that the Er,Cr:YSGG laser, in the mean powers used, is efficient for veneer removal without causing deleterious effects for the enamel.

KEYWORDS
enamel microstructure, Er,Cr:YSGG laser, lithium disilicate, optical coherence tomography, veneer

1 | INTRODUCTION

Dentistry has undergone modernization in its procedures to improve aesthetic results (Kellesarian, Malignaggi, Aldosary, & Javed, 2018). Thus, different types of dental ceramic systems were developed to meet the aesthetic expectations of patients and professionals (Tak, Sari, Malkoc, & Altintas, 2015). Advances in physical properties, mechanical properties and methods of manufacturing of ceramic materials strive to better mimic the natural dental structure (Kursoglu & Gursoy, 2013; Rechmann, Buu, Rechmann, &

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Finzen, 2014; Rechmann, Buu, Rechmann, Le, & Finzen, 2014; Sari, Tuncel, Usumez, & Gutknecht, 2014).

The lithium disilicate is a vitreous ceramic with improved properties. When compared to other kind of porcelains it has a relatively higher: strength, translucency, biocompatibility, and adhesive bonding capacity. This material is used in different types of indirect ceramic restorations, including ceramic laminates or ceramic veneers (Tak et al., 2015). The ceramic laminates were developed in the early 80s and are characterized by their thin width, offering to the patient minimally invasive dental preparations and improvement in dental aesthetics (Van As, 2013). They have become the most commonly used method in anterior indirect restorations due to their aesthetic properties (Albalkhi, Swed, & Hamadah, 2018; Iseri, Oztoprak, Ozkurt, Kazazoglu, & Arun, 2014; Sari et al., 2014). However, replacement of the ceramic laminates may be necessary due to fractures, micro-infiltrations, discoloration and their removal might be needed for aesthetic, functional and biological corrections (Iseri et al., 2014; Kursoglu & Gursoy, 2013; Sari et al., 2014; Van As, 2013).

The traditional removal of the ceramic restorations is performed by using diamond rotary instruments. However, if the professional is negligent during removal it may cause unnecessary additional wear and/or damages to the dental structure such as scratches and overheating of the enamel. Another disadvantage is the discomfort caused to the patient, since most are afraid of the famous "noise of the drill" (Kellesarian et al., 2018; Van As, 2013). After the development of the laser in the 1960s it has made great advances in several areas (Morford et al., 2011). In Dentistry, it was introduced in the early 1990s (Oztoprak, Tozlu, Iseri, Ulkur, & Arun, 2012; Van As, 2013) when it also started being used for the removal of ceramic brackets (Morford et al., 2011). After a few years, the use of lasers to remove ceramic crowns and veneers was reported. Different types of lasers were used, including Diode (Feldon, Murray, Burch, Meister, & Freedman, 2010; Yassaei, Soleimanian, & Nik, 2015), CO_2 (Ahrari, Heravi, Fekrazad, Farzanegan, & Nakhaei, 2012; Obata et al., 1999; Tehranchi et al., 2011), Nd:YAG (Han, Liu, Bai, Meng, & Huang, 2008), and Er:YAG (Alakuş-sabuncuoğlu, Erşahan, & Ertürk, 2016).

Building on the aforementioned studies and the advancement of aesthetic dentistry with ceramic laminates, further studies were developed with a purpose to evaluate the use of lasers to remove laminates. In 2011, the first articles on the subject were published by Morford et al. (2011) and Oztoprak et al. (2012). In both works the Er:YAG laser (λ = 2,940 nm) was used. Before the present work, the efficiency of laser for removal of porcelain laminated veneers had not been investigated. Morford et al. (2011) used the repetition rate of 10 Hz, pulses of 100 μs and energy per pulse of 133 mJ. Additionally, to remove RelyX Veneer resin cement, lithium disilicate and E-max laminates, non-contact laser tip distance of 3–6 mm was used and the average irradiation for removal time was 106 ± 59 s. The authors performed the Fourier-Transformed Infrared Spectroscopy (FTIR) after the irradiations and verified that the Er:YAG laser was not strongly absorbed by the ceramic materials so, could be transmitted through the laminates. On the other hand, Oztoprak et al. (2012) used the Er:YAG laser (5 W, 50 Hz, 100 mJ/pulse with a 1 mm diameter tip at a 2 mm distance from the surface of the laminates) during 3, 6, and 9 s for debonding Variolink Veneer resin cement and lithium disilicate. The authors showed that the irradiated ceramic laminates had lower shear bond strength.

The Er,Cr:YSGG laser is also widely used in dentistry and, among other applications, has been used to remove ceramic veneers (Gurney, Gurney, Sharples, Phillips, & Lee, 2016). It is a laser that also has photoablation effects, but with some differences in relation to Er:YAG laser, since it is more highly absorbed by hydroxyapatite OH^- ion and water (Seka, Featherstone, Fried, Visuri, & Walsh, 1996). Although it is a versatile equipment, there have been no specification stating whether it can also be used to remove ceramic veneers without causing structural damage to the enamel, which, motivated this study.

Thus, this work aims to evaluate two different mean powers of the Er,Cr:YSGG laser for removal of ceramic veneers cemented with three different resin cements. For this evaluation, the morphological, elemental and optical aspects of the dental enamel were studied before and after the removal of the ceramic laminates with laser. The null hypothesis considered was that laser irradiation does not cause morphological, optical or compositional changes in the enamel during the debonding procedure.

2 | MATERIALS AND METHODS

2.1 | Experimental design

After the approval from the Ethics Committee of the School of Dentistry from the University of São Paulo (CEP-FOUSP CAAE: 97050218.6.0000.0075), 11 human third molar teeth were decontaminated, sliced and embedded in acrylic resin, had their enamel surface flattened and polished. Lithium disilicate laminates were cemented to the enamel surfaces using three different resin cements: Variolink Veneer, RelyX Veneer, and RelyX U200. Er,Cr:YSGG laser, at two different protocols, was used for debonding the laminates. The enamel surface was analyzed by energy-dispersive X-ray spectroscopy (EDS), scanning electron microscopy (SEM), and optical coherence tomography (OCT) before cementation and after debonding the laminates. The statistical analysis was performed individually for each response variable considering the laser protocols and cements as variation factors and the enamel slabs as the experimental units, at 5% significance level.

2.2 | Preparation of enamel

Eleven human molar teeth were cleaned and immersed in thymol solution for 48 hr (White et al., 1993; White, Fagan, & Goodis, 1994). After, each tooth was sectioned using a high-speed handpiece (Gnatus, PR, Brazil), a multilaminated bur (KG Sorensen, SP, Brazil) and distilled water spray. The roots were removed and the crowns were cut in four parts of 7 × 7 mm. The slabs were embedded in acrylic resin, flattened and polished. Baseline surface microhardness was measured using a *Knoop* microhardness tester (HMV 2T, Shimadzu Scientific Instruments, Japan), in which 10 indentations were performed at the center of the enamel surface, using 25-g load for 10s. Slabs with 360 and 420 KHN (Knoop hardness number) (Argenta, Tabchoury, & Cury, 2007) were selected and randomly distributed in the nine experimental groups of this study.

2.3 | Experimental groups

Samples were randomly distributed in nine experimental groups, according to Table 1.

2.4 | Cementation of lithium disilicate laminates

Three types of resin cements were used for cementation of standardized $3 \times 3 \times 0.7$ mm lithium disilicate laminates (IPS e.max CAD; Ivoclar Vivadent Inc.): Variolink Veneer (Ivoclar Vivadent), RelyX U200 (3M) and RelyX Veneer (3M). These laminates were manufactured by a specialized prosthetics laboratory in order to simulate a clinical laminate veneer and were blasted with zinc oxide by 120 μm in the Bijato Renfert® equipment. The resin cements were applied to the enamel and laminates following the cementation instructions from the manufacturers, as detailed in Table 2.

The cement thickness was standardized using a customized device for this study, as noted in Figure 1.

2.5 | Debonding parameters

The samples were stored according to the guidelines of ISO/TS11405:2015 (distilled and deionized water, at a controlled temperature of 37°C) and debonded 24 hr after being cemented. The Er,Cr:YSGG WaterLaser (Biolase, San Clemente), wavelength of 2.78 μm, pulse width of 140 μs and repetition rate of 20 Hz was used in this study. In order to standardize the irradiations, a high-precision motorized translator (ESP300; Newport Corporation) was used adjusted to a speed of 4 mm/s, and this speed was chosen in order to avoid overlap of pulses or absence of irradiation. The distance between each irradiation line was 600 μm to ensure uniform irradiation (Benetti, Ana, Bachmann, & Zezell, 2015). Two irradiation protocols were tested, both used the MGG6-4 mm sapphire tip (Biolase, San Clemente) at a diameter of 0.6 mm and a focal length of 1 mm (non-contact). Irradiation was performed using irrigation of distilled and deionized water, with a ratio of 60% air and 40% water, which follows the scanning method described by Oztoprak et al. (2012). The laser parameters used

TABLE 2 Cementation protocol (following the manufacturer guidelines)

Cement	Cementation protocol
Variolink Veneer	In laminate veneer 1. Condition with 10% Dentsply Sirona hydrofluoric acid for 20 s 2. Washing to rinsing with air jet and distilled water 3. Apply Monobond Plus, recommended material by the manufacturer for 60 s, after which it dries for 5 s. Tooth surface 1. Condition with 37% phosphoric acid from Dentsply Sirona for 20 s 2. Washing to rinsing with air jet and distilled water 3. Application of Tetric N-bond, an adhesive system recommended by the manufacturer. We dry and light cure for 10 sec using the Radi Call light cure
RelyX U200	Intaglio surface of the veneer 1. Conditioning with 10% Dentsply Sirona hydrofluoric acid for 20 s. 2. Washing to rinsing with air jet and distilled water Tooth surface 1. Wash and remove excess moisture
RelyX Veneer	Intaglio surface of the veneer 1. Conditioning with 10% Dentsply Sirona hydrofluoric acid for 20 s. 2. Washing to rinsing with air jet and distilled water 3. Apply the single bond universal and air jet (do not photopolymerize) Tooth surface 1. Condition with 37% phosphoric acid from Dentsply Sirona for 20 s 2. Washing to rinsing with air jet and distilled water 3. Application of single bond universal for 20 s, air jet for 5 s (do not photoactivate)

TABLE 1 Experimental groups of this study

Group	Cement	Debonding	
G1	Variolink Venner	No laser	
G2		Laser	3.5 W/48.14 J/cm^2/20 Hz/no contact
G3		Laser	3.0 W/40 J/cm^2/20 Hz/no contact
G4	RelyX U200	No laser	
G5		Laser	3.5 W/48.14 J/cm^2/20 Hz/no contact
G6		Laser	3.0 W/40 J/cm^2/20 Hz/no contact
G7	RelyX Veneer	No laser	
G8		Laser	3.5 W/48.14 J/cm^2/20 Hz/no contact
G9		Laser	3.0 W/40 J/cm^2/20 Hz/no contact

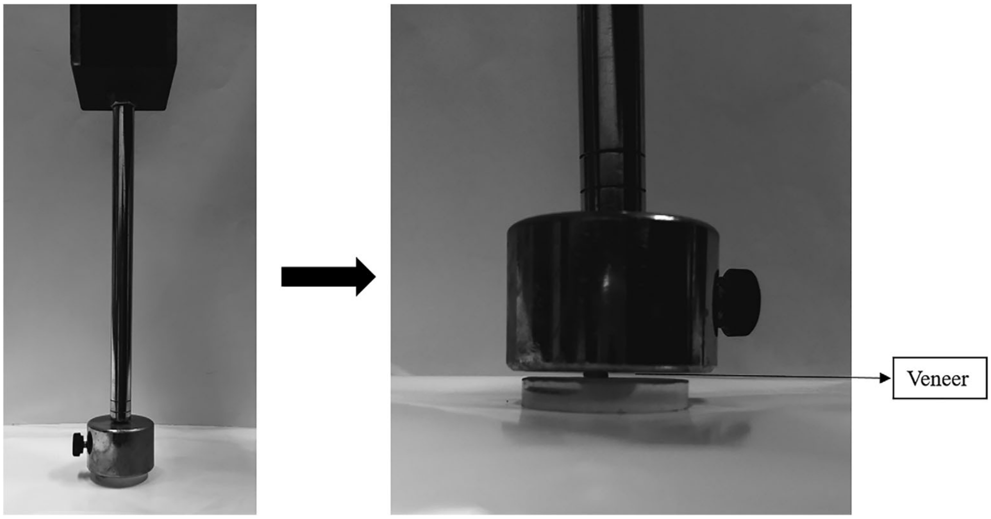

FIGURE 1 Device used to standardize the thickness of the resin cement

in this study were confirmed with a powermeter before each irradiation (Coherent Fieldmaster GS, Newport).

In groups that were not debonded using the laser, an Instron Universal Testing Machine was used for a shear bond strength test. The shear force was applied to the laminate-tooth interface, at a cross-head speed of 0.5 mm/min, with a load of 10 Kgf and a 0.2 mm chisel shape (Odeme Dental Research®, Santa Catarina, Brazil) until fracture.

2.6 | Optical analysis

The optical analysis was performed by OCT imaging on enamel surface before cementation of laminates and after debonding. The Callisto 930 nm OCT Imaging System with an axial resolution of 7 μm, transversal resolution of 8 μm and maximum penetration depth of 1.71 mm in air was utilized in this study. From each sample, 3 images (B-scans) were obtained with one in the center and the other two at a 0.5 mm distance from each other. A routine was developed in MATLAB (MathWorks) to process the OCT files, obtaining the optical attenuation coefficients (μ) automatically through the exponential decay of intensities along the depth (A-scan).

2.7 | Morphological analysis

The morphological analysis of enamel surface was performed before cementation and after debonding by Scanning Electron Microscopy (SEM, TM 3000 Tabletop Microscope, Hitachi, Japan) under low vacuum. Samples were mounted in aluminum stubs with a conductive carbon tape (Electron Microscopy Sciences, PA) and inspected by a blind single operator. For the evaluation of the elemental composition of the surfaces, an energy-dispersive spectrometer system attached to the SEM device was used. The hydroxyapatite components (Ca and P) and the main compounds from the cementing agents such as C and Si were analyzed.

2.8 | Statistical analysis

The statistical analysis was performed individually for each response variable (μ, Ca, P, C, and Si) while considering laser irradiation (no laser, laser at 3 W and laser at 3.5 W) and cement (Variolink Veneer, RelyX U200 and RelyX Veneer) as variation factors. The assumptions of independence, normality and homogeneity of the obtained sample data were tested using the Shapiro–Wilk and Bonferroni tests. For each analysis, different tests were employed according to the factors to be compared and distribution of the sample data, which will be detailed in the next section. In order to employ different tests, the GraphPad Prism 8 software was used considering the level of significance of 5%.

3 | OPTICAL ANALYSIS

Figure 2 shows representative OCT images (B-scans) of the unlased groups before cementation of the ceramic veneer (A) and after non-laser debonding (B). It is possible to notice a visible white line between air and enamel, evidencing the flatten surface. This line becomes quite irregular in image 2B, where surface projections (arrows) can be seen which is an indicative of the remainder of RelyX U200 resin cement.

Figure 3 shows a representative B-scan obtained from enamel before cementation (Figure 3a) and after laser debonding (Figure 3b). A flatten surface is seen before cementation and, after debonding, there is an irregular surface due to the remaining RelyX Veneer cement (arrows). In addition, the remaining enamel is more whitish, which suggests greater light scattering after debonding.

The results of the optical attenuation coefficients (μ) are showed in Figure 4 and in Table 3. An increase of μ values after debonding is observed in all experimental groups, except for the G5 (bonded with RelyX U200 cement and debonded with laser 3.5 W) and G7 (bonded with RelyX Veneer and debonded without laser) groups. When comparing the differences (Δμ) among groups, it was detected that only the G7 group presented statistically lower Δμ (Kruskal–Wallis + Dunn

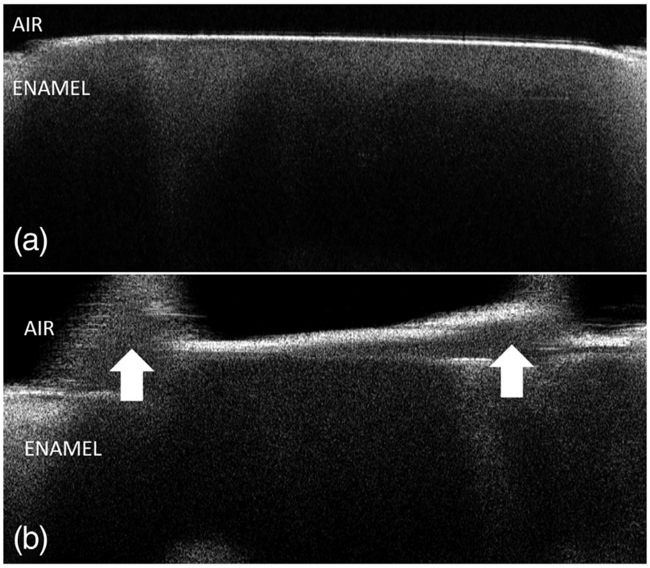

FIGURE 2 Representative OCT images from an unlased sample. (a) Before cementation of the ceramic laminate; (b) after removal of ceramic laminate. Arrows evidence the remains of resin cement from RelyX U200

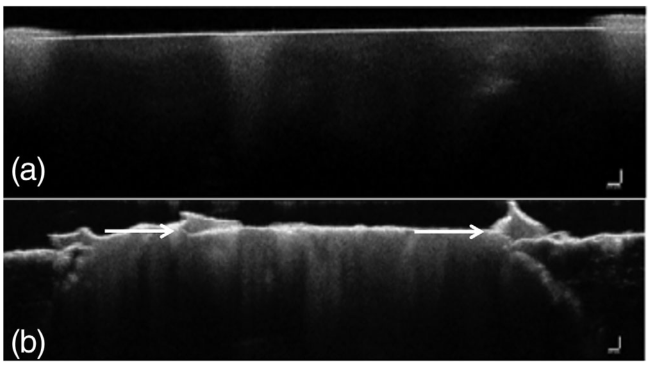

FIGURE 3 Representative OCT images from a lased sample. (a) Before laser irradiation showing a polished human enamel surface and (b) after Er,Cr:YSGG laser irradiation showing debris of the used RelyX Veneer cement

test) when compared to the G8 and G9 groups (groups that were cemented with the same RelyX Veneer cement).

3.1 | Morphological analysis

Figure 5 shows the SEM images of the unlased samples, before cementation of the ceramic laminates and after their removal. Before cementation, flattened surfaces and the enamel's prisms are seen. After debonding, in all images residual cement is observed on their surface (asterisks) and the enamel's prisms are not visible.

Figure 6 shows SEM images of every experimental group before and after laser debonding, for each cement used. It can be noted that ceramic laminates are not present on the surface, there is only remnants of resin cement. The presence of cement residues was observed in all experimental groups (asterisks) and the exposition of the enamel's prisms on images 6D and 6F can be noticed (circles).

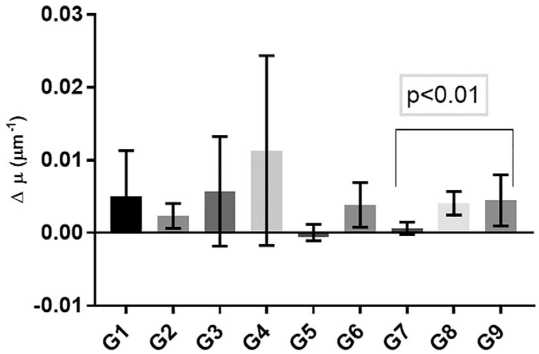

FIGURE 4 Differences in the optical attenuation coefficients values in all experimental groups. Bars evidence standard deviations. The *p* value denotes statistical differences according to Kruskal–Wallis + Dunn test

Figure 7 shows an image of enamel before cementation (Figure 7a) and after debonding (Figure 7b), in lower magnification (500X). The path taken by laser irradiation on the resin cement surface can be noted (Figure 7b). In this way, it is possible to observe integral enamel prisms.

3.2 | Elemental analysis

The elemental analysis of the human dental enamel performed before the lithium disilicate bonding and then after Er,Cr:YSGG laser debonding showed significant differences at the intra group comparison (Kruskal–Wallis + Student–Newmann–Keuls test, $p < 0.05$). After debonding it was possible to detect other elements that are presents in the cements used (P and Si), as shown in Figure 7.

It is noticed that the contents of calcium and phosphorous were similar among all experimental groups ($p > 0.05$) before cementation of the veneers. However, after debonding, the percentages of these elements were significantly decreased in all experimental groups, except for the G7 group (veneers cemented using RelyX Veneers and debonded without laser). Concerning the contents of P and Si, it was observed that they were not detected in the enamel before cementation in all experimental groups. Nonetheless, there was a significant increase ($p < 0.05$) in the percentage of these elements in the enamel after debonding in all experimental groups, except in the G7 group.

When comparing the carbon contents after debonding within group, it was evidenced that groups G1, G4, and G8 presented statistically higher percentages than the other experimental groups, while group G7 presented the lowest percentage. When comparing the percentages of Si, it was observed that the groups G4, G8, and G9 presented significantly upper values than the other experimental groups, while the group G7 presented the lowest percentage. Also, in group G7, Ca and P values after debonding were significantly higher than all other experimental groups (Figure 8).

Experimental group	Before cementation	After debonding	Statistical test	*p* value
G1	0.0021 ± 0.0005	0.0071 ± 0.0061	Wilcoxon	0.0171
G2	0.0013 ± 0.0004	0.0037 ± 0.0015	Wilcoxon	0.0017
G3	0.0019 ± 0.0003	0.007 ± 0.0076	Wilcoxon	0.002
G4	0.0024 ± 0.0004	0.0137 ± 0.0131	Wilcoxon	0.0068
G5	0.0018 ± 0.0005	0.0018 ± 0.0010	*t* test	0.9074
G6	0.0022 ± 0.0018	0.0060 ± 0.0023	*t* test	0.0019
G7	0.0020 ± 0.0002	0.0026 ± 0.0007	Wilcoxon	0.1094
G8	0.0024 ± 0.0006	0.0064 ± 0.0016	Wilcoxon	0.0010
G9	0.0022 ± 0.0005	0.0067 ± 0.0034	Wilcoxon	0.0006

TABLE 3 Mean ± SD values of optical attenuation coefficients before cementation and after debonding, as well as the statistical test performed and *p* values obtained for each experimental group

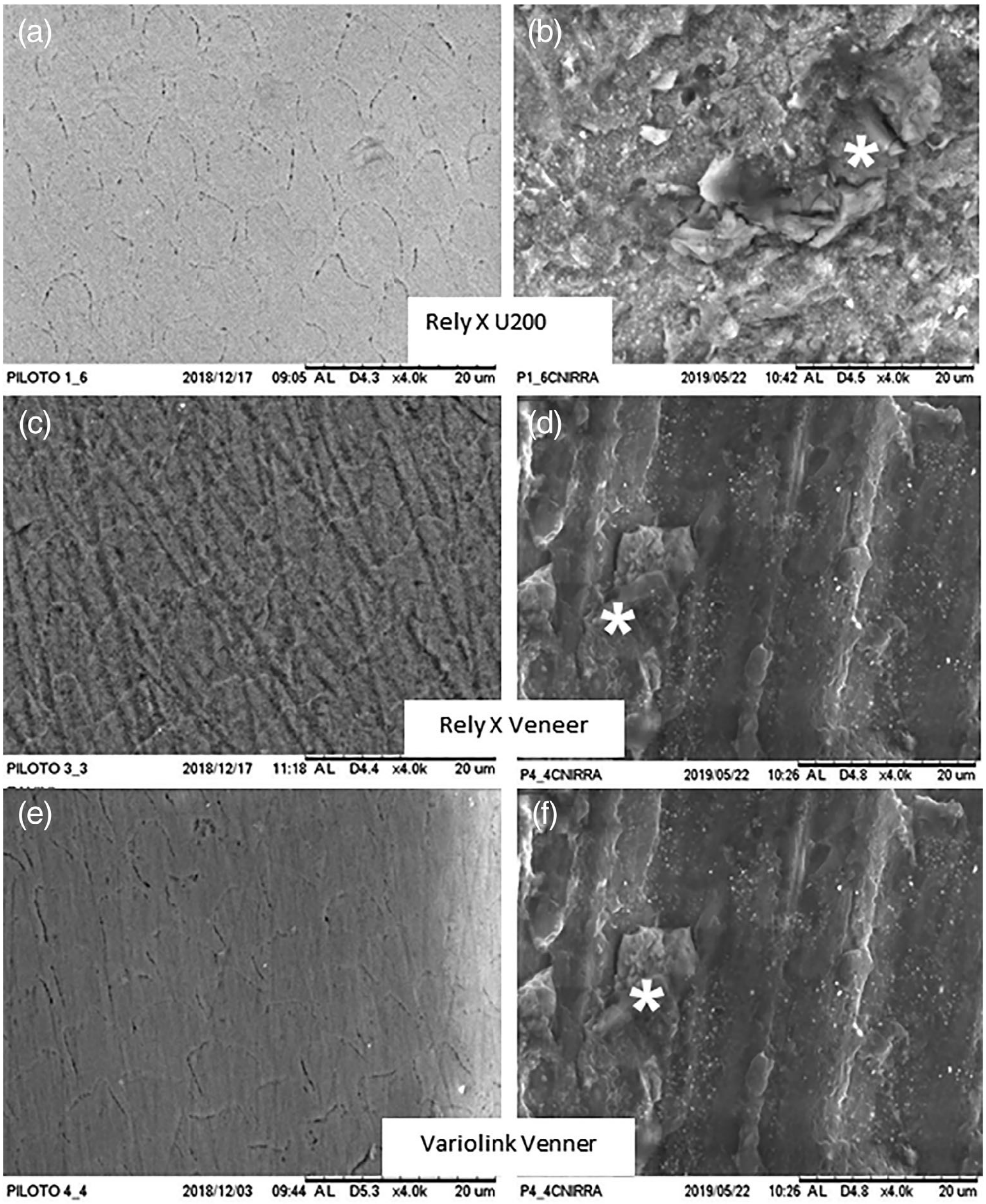

FIGURE 5 Representative electromicrographs of all experimental groups before cementation (images a, c, and e) and after debonding (images b, d, and f). The asterisks evidence remnants of the cements used after debonding. Original magnification: 4,000X

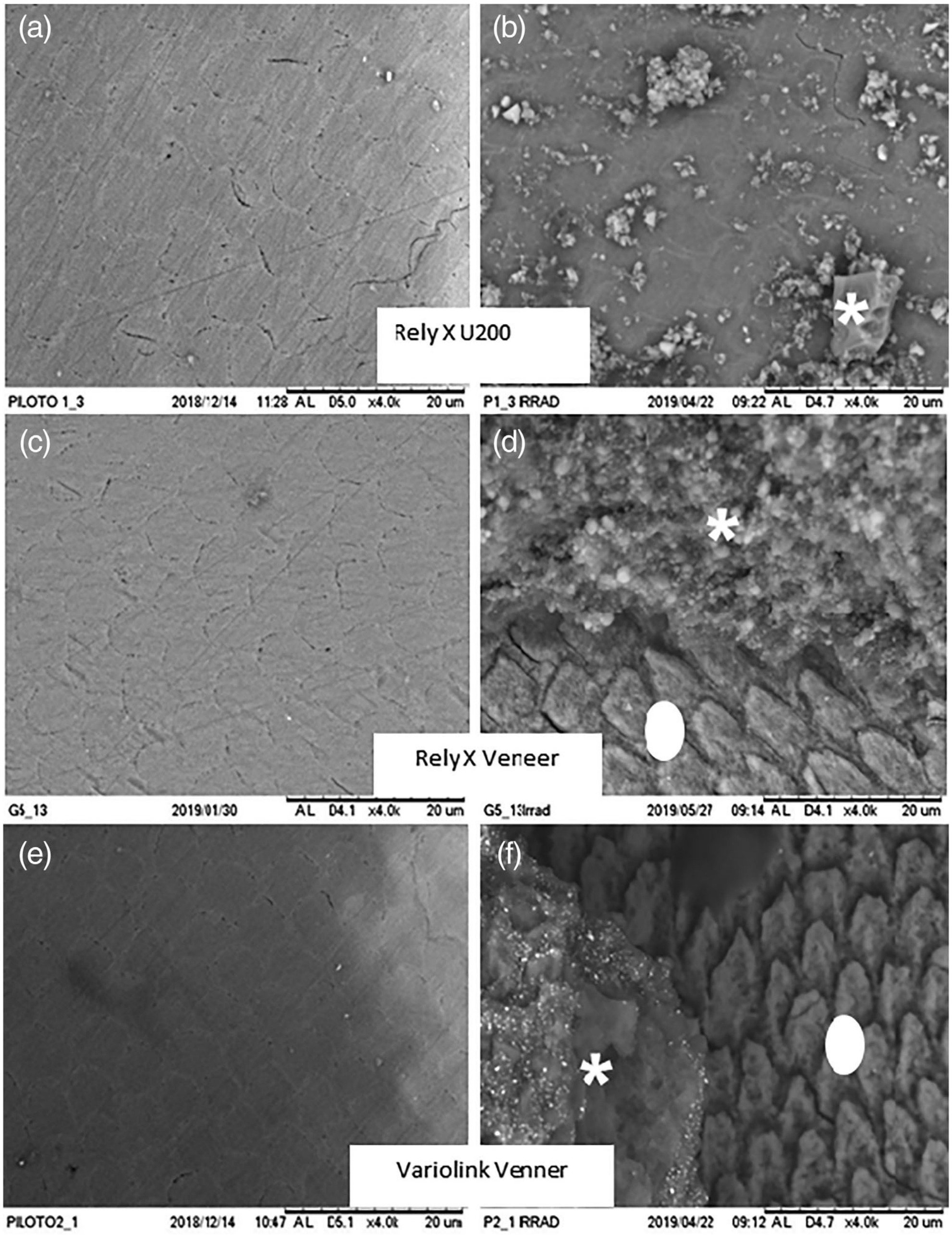

FIGURE 6 Representative electromicrographs of all experimental groups before cementation (images a, c, and e) and after debonding with laser (images b, d, and f). Original magnification: 4,000X. The asterisks evidence remnants of the cements used after debonding and the circles denote the enamel's prisms exposed after debonding

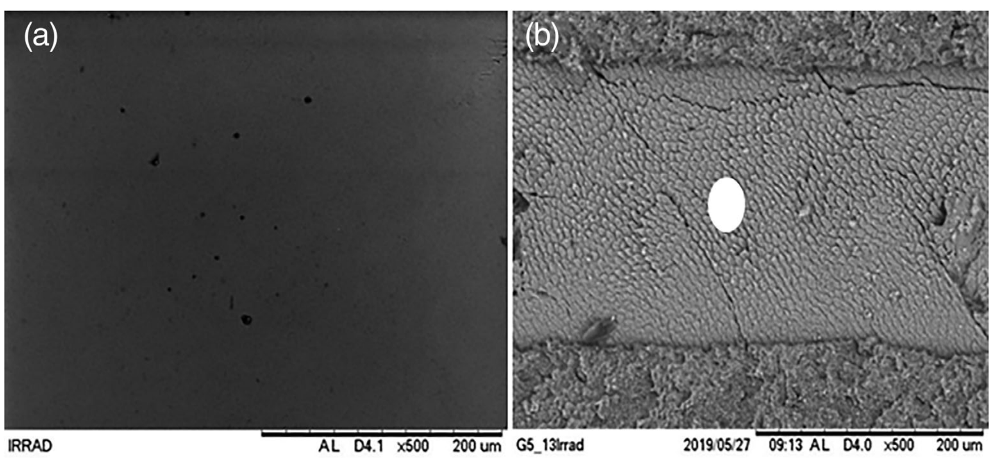

FIGURE 7 Representative electromicrographs performed before (a) and after (b) irradiation, illustrating Er,Cr:YSGG laser photoablation only in resin cement and the exposition of the enamel prisms (b)

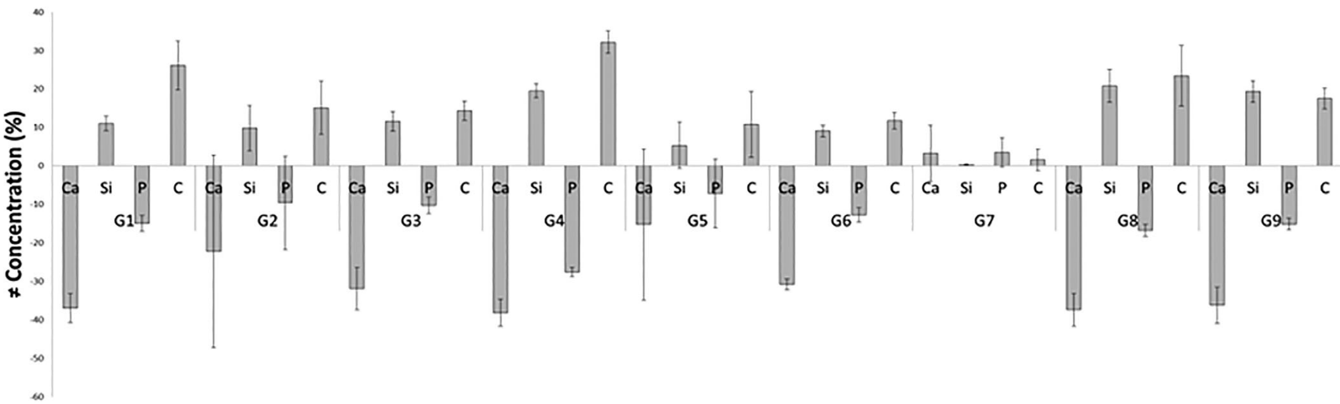

FIGURE 8 Means and standard deviation of the percentage of Ca, Si, P, and C contents in the samples of all experimental before lithium disilicate cementation and after the debonding

4 | DISCUSSION

Contemporary dentistry is a challenge, since patients need excellent dental treatment, aiming at desirable aesthetics and with a minimally invasive approach. Aesthetically pleasing restorative materials are launched every year to provide dentists with tools that offer "ideal aesthetics" to their patients. Ceramic laminates are being widely used in dentistry because they require minimally invasive preparations and promise the so-called "natural aesthetics" for patients (Kursoglu & Gursoy, 2013). However, replacement of laminates may be necessary over the years. Traditionally, high speed diamond drills are used to remove veneers but, since 2011 laser irradiation has been tested for this purpose. Studies have focused on the use of the Er:YAG laser (Morford et al., 2011; Oztoprak et al., 2012). The differential of the present study is the use of the Er,Cr:YSGG laser to remove the lithium disilicate laminates and, after removal, evaluate whether the laser irradiation promotes morphological, optical and elementary changes to the remaining enamel. For that, three types of cement were used: RelyX U200 (auto-adhesive dual cement), RelyX Veneer (total-etch) and Variolink Veneer (total-etch). However, the type of cement used did not appear to significantly alter bond strength, since resin cement remnants were found in all enamel samples. SEM and EDS analysis confirmed the remaining resin cement on the enamel surface, for all groups except the G7 Group. The analysis by EDS showed a significant decrease in the percentage of calcium and phosphate after debonding in practically all experimental groups (except for G7 group). This indicates that cement is present on the surfaces and therefore, prevents the detection of the main components of hydroxyapatite. Even so, there was a significant increase in the percentages of carbon and silicon (components of resin cements) which, once again, reinforces presence of cement in the enamel after debonding. In the G7 group, however, the results were the opposite, suggesting that the resin cement was removed in its entirety during the debonding (Lee et al., 2015). In groups G8 and G9, the same adhesive system used in G7 showed a greater amount of cement remnant. Although the SEM does not show changes to the enamel prisms, the data generated by the OCT (optical attenuation coefficient) suggests an increase in temperature during irradiation.

One of the goals was to check if the laser had an ablative effect on the enamel prisms. Fortunately, its effect was only noticed on cement, without causing morphological changes to the enamel. The Er,Cr:YSGG laser is highly absorbed by OH^- ions from water and hydroxyapatite, which are the main components of enamel and can cause physical changes, such as ablation (Quinto et al., 2017), depending on the temperature rises during irradiations. For the occurrence of ablative effects, temperature increases of 800°C must be achieved (Seka et al., 1996). However, chemical effects can be observed at temperatures above 100°C, such as water evaporation, carbonate removal or denaturation of the organic matrix. Therefore, even in the absence of ablative effects, there may have been heating on the enamel surface that did not result in morphological changes (Fowler & Kuroda, 1986). Although these thermal effects are well known in enamel and dentin, nothing is known about the thermal effects on the cements used in the present study.

Considering these aspects, the fact that there is no cement residue in group G7 (RelyX Veneer, not irradiated), but there is a remainder of cement in groups G8 and G9 (RelyX Veneer, but with laser irradiation) suggests that the heat generated during irradiations may have chemically modified this cement, fluidizing it and making it more retained on the enamel surface. A study by Morford et al. (2011) showed that this cement has an H_2O/OH absorption band (at 3,750–3,640 and 3,600–3,400 cm^{-1}, respectively), which are very close with the Er,Cr:YSGG laser emission wavelength. Thus, the absorption of photons was more accentuated in this cement, which may justify the thermal changes observed.

Photoablation is an explosive removal process that causes a material to be ejected. In Figures 6 and 7, it is observed that photoablation occurred only in the resin cement and, the enamel prisms remained intact. In Figure 5, the morphological changes of the enamel prisms in the groups cemented with Variolink Veneer and RelyX Veneer can be observed. These changes were not observed when using RelyX U200 cement, which is an auto-adhesive dual system.

This shows that the changes promoted on the enamel surface in groups cemented with Variolink Veneer and RelyX Veneer are mainly due to the acid conditioning (Gandhi, Kalra, Goyal, & Sharma, 2018), and not by the heat generated by the laser. To be sure of this statement, we used an auto-adhesive dual cement for comparison despite this cement not being indicated by the manufacturer for the use on veneer cementation. The goal was to remove any doubts related to the morphological alteration that occurred in the enamel, that is, not to erroneously conclude that this alteration could have caused by the increase in temperature due to laser irradiation. The absence of morphological changes in enamel after RelyX U200 debonding demonstrated that the change in the prisms observed after debonding at Variolink Veneer and RelyX Veneer groups is justified by the acid conditioning present in these total etch systems. There were also no other morphological changes that could be due to heating, such as cracks, melting or carbonization. These findings confirm our null hypothesis.

There were optical changes observed by OCT analysis. OCT (Optical Coherence Tomography) is a nondestructive, noninvasive and non-contact diagnostic method for analyzing images of cross-sections of biological systems, first described in 1991 by Huang et al. (1991). This technique uses the backscattered signal to obtain optical information from biological tissues, which are related to its chemical composition, microstructural organization, roughness and other morphological aspects. The calculation of the optical attenuation coefficient is related to the loss of enamel and dentin microhardness, and, is often associated with the analysis of caries lesions. In addition, it may be related to chemical changes resulting from heating, such as those caused by high-power lasers (Cara, Zezell, Ana, Maldonado, & Freitas, 2014). In the present work, we observed a significant increase in the optical attenuation coefficient values in most experimental groups after debonding except in G5 and G7 ones. This fact can be justified in two ways. First, part of the resin cement remained on the surfaces, preventing the passage of light or increasing the light scattering and, consequently, increasing the optical attenuation coefficient. On the other hand, the heat generated by the laser irradiation may have caused a chemical change in the interprismatic spaces, since the images generated by the OCT show a more whitish area (Figures 2 and 3). This chemical change depends on the rise in temperature and begins mainly with the removal of water and carbonate (Fowler & Kuroda, 1986). Therefore, the interprismatic remodeling observed in the images shows us that the laser can cause some modifications in these prisms; however, it was not enough to change the morphology of the surface. Although two different irradiation protocols were used, no significant differences in effects were observed between them.

At the time of irradiation of the samples, we observed that regardless of the laser protocol used, there was no difference in the time taken for debonding of the veneers. Practically all the veneers of the irradiated groups were removed as a whole, without cracks or fractures and, in a maximum time of 30 s. The removal time was reduced in the groups that were cemented with RelyX U200. It is believed that this short time probably occurred due to the type (Emax) and dimension ($3 \times 3 \times 0.7$ mm) of the ceramic fragments used. We can consider this a limitation of this study since the laminates tested were not to similar size as that used for aesthetic rehabilitation in patients. Clinically, changes in time and also in the integrity of the laminates during removal can occur mainly due to the cavity preparation, differences in the thickness of the cements or even in the type of material used in the construction of the laminate (feldspar, Emax and others).

Therefore, according to the observed results, it can be suggested that both laser protocols are effective in removing veneers and do not cause harmful morphological and microstructural effects to the enamel. This was because air-water coolant was used in all irradiations which prevented excessive heating. Further studies are necessary to know whether the increases in temperature reached during removal laminate veneer cause pulp damage, and if it is safe to indicate these protocols for future clinical application.

Nowadays, patients are looking for aesthetic rehabilitation treatments at an earlier age. We are living a moment in dentistry in which patients tirelessly seek an “ideal” aesthetic. However, the sooner patients are submitted to “invasive” aesthetic procedures, the greater the chances of need for retreatment throughout life. Considering this fact, the use of laser irradiation with adequate parameters for the removal of laminates can be considered a benefit. It reduces the risk of damage to the enamel surface caused by removal with diamond drills and generates less discomfort. However, caution should be exercised, as there are few studies that prove that it is really effective without causing damage to the substrate and that it leaves this substrate with ideal conditions for new adhesive cementations.

5 | CONCLUSION

The Er,Cr:YSGG laser is effective for removing lithium disilicate laminates without causing damage and photoablation in enamel prisms. The presence of cement remnants after debonding, detected by OCT and EDS techniques, evidences the thermal and ablative effects promoted by irradiations only in the cement layer, which suggest that the protocols used may be suitable for future clinical application.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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REFERENCES

Ahrari, F., Heravi, F., Fekrazad, R., Farzanegan, F., & Nakhaei, S. (2012). Does ultra-pulse CO_2 laser reduce the risk of enamel damage during debonding of ceramic brackets? *Lasers in Medical Science*, *27*, 567–574. https://doi.org/10.1007/s10103-011-0933-y

Alakuş-sabuncuoğlu, F., Erşahan, S., & Ertürk, E. (2016). Debonding of ceramic brackets by Er:YAG laser. *Journal of Istanbul University Faculty of Dentistry*, *50*, 24–30. https://doi.org/10.17096/jiufd.39114

Albalkhi, M., Swed, E., & Hamadah, O. (2018). Efficiency of Er:YAG laser in debonding of porcelain laminate veneers by contact and non-contact laser application modes (in vitro study). *Journal of Esthetic and Restorative Dentistry*, *30*, 223–228. https://doi.org/10.1111/jerd.12361

Argenta, R. M. O., Tabchoury, C. P. M., & Cury, J. A. (2007). A modified pH-cycling model to evaluate fluoride effect on enamel demineralization. *Pesquisa Odontológica Brasileira*, *17*, 241–246. https://doi.org/10.1590/s1517-74912003000300008

Benetti, C., Ana, P. A., Bachmann, L., & Zezell, D. M. (2015). Mid-infrared spectroscopy analysis of the effects of erbium, chromium:yattrium-scandium-gallium-garnet (Er,Cr:YSGG) laser irradiation on bone mineral and organic components. *Applied Spectroscopy*, *69*, 1496–1504. https://doi.org/10.1366/14-07726

Cara, A. C. B., Zezell, D. M., Ana, P. A., Maldonado, E. P., & Freitas, A. Z. (2014). Evaluation of two quantitative analysis methods of optical coherence tomography for detection of enamel demineralization and comparison with microhardness. *Lasers in Surgery and Medicine*, *46*, 666–671. https://doi.org/10.1002/lsm.22292

Feldon, P. J., Murray, P. E., Burch, J. G., Meister, M., & Freedman, M. A. (2010). Diode laser debonding of ceramic brackets. *American Journal of Orthodontics and Dentofacial Orthopedics*, *138*, 458–462. https://doi.org/10.1016/j.ajodo.2008.11.028

Fowler, B. O., & Kuroda, S. (1986). Changes in heated and in laser-irradiated human tooth enamel and their probable effects on solubility. *Calcified Tissue International*, *38*(4), 197–208. https://doi.org/10.1007/bf02556711

Gandhi, G., Kalra, J. P. S., Goyal, A., & Sharma, A. (2018). Microphotographic assessment of enamel surface using self-etching primer and conventional phosphoric acid: An in vitro study. *Contemporary Clinical Dentistry*, *9*, 15–19. https://doi.org/10.4103/ccd.ccd_647_17

Gurney, M. L., Sharples, S. D., Phillips, W. B., & Lee, D. J. (2016). Using an Er, Cr:YSGG laser to remove lithium disilicate restorations: A pilot study. *Journal of Prosthetic Dentistry*, *115*, 90–94. https://doi.org/10.1016/j.prosdent.2015.08.003

Han, X., Liu, X., Bai, D., Meng, Y., & Huang, L. (2008). Nd:YAG laser-aided ceramic brackets debonding: Effects on shear bond strength and enamel surface. *Applied Surface Science*, *255*, 613–615. https://doi.org/10.1016/j.apsusc.2008.06.082

Huang, D., Swanson, E. A., Lin, C. P., Schuman, J. S., Stinson, W. G., Chang, W., … Fujimoto, J. G. (1991). Optical coherence. *Science*, *254*, 1178–1181. https://doi.org/10.1126/science.1957169

Iseri, U., Oztoprak, M. O., Ozkurt, Z., Kazazoglu, E., & Arun, T. (2014). Effect of Er:YAG laser on debonding strength of laminate veneers. *European Journal of Dentistry*, *8*, 58–62. https://doi.org/10.4103/1305-7456.126243

Kellesarian, S. V., Malignaggi, V. R., Aldosary, K. M., & Javed, F. (2018). Laser-assisted removal of all ceramic fixed dental prostheses: A comprehensive review. *Journal of Esthetic and Restorative Dentistry*, *30*, 216–222. https://doi.org/10.1111/jerd.12360

Kursoglu, P., & Gursoy, H. (2013). Removal of fractured laminate veneers with Er:YAG laser: Report of two cases. *Photomedicine Laser Surgery*, *31*, 41–43. https://doi.org/10.1089/pho.2012.3410

Lee, S.-E., Bae, J.-H., Choi, J.-W., Jeon, Y.-C., Jeong, C.-M., Yoon, M.-J., & Huh, J.-B. (2015). Comparative shear-bond strength of six dental self-adhesive resin cements to zirconia. *Materials (Basel)*, *8*, 3306–3315. https://doi.org/10.3390/ma8063306

Morford, C. K., Buu, N. C. H., Rechmann, B. M. T., Finzen, F. C., Sharma, B., & Rechmann, P. (2011). Er:YAG laser debonding of porcelain veneers. *Lasers in Surgery and Medicine*, *974*, 965–974. https://doi.org/10.1002/lsm.21144

Obata, A., Tsumura, T., Niwa, K., Ashizawa, Y., Deguchi, T., & Ito, M. (1999). Super pulse CO_2 laser for bracket bonding and debonding. *European Journal of Orthodontics*, *21*, 193–198. https://doi.org/10.1093/ejo/21.2.193

Oztoprak, M. O., Tozlu, M., Iseri, U., Ulkur, F., & Arun, T. (2012). Effects of different application durations of scanning laser method on debonding strength of laminate veneers. *Lasers in Surgery and Medicine*, *27*, 713–716. https://doi.org/10.1007/s10103-011-0959-1

Quinto, J. J., Amaral, M. M., Francci, C. E., Ana, P. A., Moritz, A., & Zezell, D. M. (2017). Evaluation of intra root canal Er,Cr:YSGG laser irradiation on prosthetic post adherence. *Journal of Prosthodontics*, *28*, 181–185. https://doi.org/10.1111/jopr.12609

Rechmann, P., Buu, N. C. H., Rechmann, B. M. T., & Finzen, F. C. (2014). Laser all-ceramic crown removal—A laboratory proof-of-principle study—Phase 2 crown debonding time. *Lasers in Surgery and Medicine*, *46*, 636–643. https://doi.org/10.1002/lsm.22280

Rechmann, P., Buu, N. C. H., Rechmann, B. M. T., Le, C. Q., Finzen, F. C., & Featherstone, J. D. B. (2014). Laser all-ceramic crown removal—A laboratory proof-of-principle study—Phase 1 material characteristics. *Lasers in Surgery and Medicine*, *46*, 628–635. https://doi.org/10.1002/lsm.22279

Sari, T., Tuncel, I., Usumez, A., & Gutknecht, N. (2014). Transmission of Er:YAG laser through different. *Photomedicine and Laser Surgery*, *32*, 37–41. https://doi.org/10.1089/pho.2013.3611

Seka, W., Featherstone, J. D. B., Fried, D., Visuri, S. R., & Walsh, J. T. (1996). Laser ablation of dental hard tissue: From explosive ablation to plasma-mediated ablation. *Lasers in Dentistry II*. *2672*, 144–158. https://doi.org/10.1117/12.238763

Tak, O., Sari, T., Malkoc, A. M., & Altintas, S. (2015). The effect of transmitted Er:YAG laser energy through a dental ceramic on different types of resin cements. *Lasers in Surgery and Medicine*, *47*, 602–607. https://doi.org/10.1002/lsm.22394

Tehranchi, A., Fekrazad, R., Zafar, M., Eslami, B., Kalhori, K. A. M., & Gutknecht, N. (2011). Evaluation of the effects of CO_2 laser on debonding of orthodontics porcelain brackets vs. the conventional method. *Lasers in Medical Science*, *26*, 563–567. https://doi.org/10.1007/s10103-010-0820-y

Van As, G. A. (2013). Using the erbium laser to remove porcelain veneers in 60 seconds. *Journal of Cosmetic Dentistry*, *28*, 20–34.

White, J. M., Fagan, M. C., & Goodis, H. E. (1994). Intrapulpal temperatures during pulsed Nd:YAG laser treatment of dentin, in vitro. *Journal of Periodontology*, *65*, 255–259. https://doi.org/10.1902/jop.1994.65.3.255

White, J. M., Goodis, H. E., Setcos, J. C., Eakle, W. S., Eakle, S., Hulscher, B. E., & Rose, C. L. (1993). Effects of pulsed Nd:YAG laser energy on human teeth: A three-year follow-up study. *The Journal of the American Dental Association*, *124*, 45–51. https://doi.org/10.14219/jada.archive.1993.0273

Yassaei, S., Soleimanian, A., & Nik, Z. E. (2015). Effects of diode laser debonding of ceramic brackets on enamel surface and pulpal temperature. *The Journal of Contemporary Dental Practice*, *16*, 270–274. https://doi.org/10.5005/jp-journals-10024-1674

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