

Evaluation of Er:YAG and Er,Cr:YSGG laser irradiation for the debonding of prefabricated zirconia crowns

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Abstract

Background. Reduced tooth structure in the pediatric and adolescent population is frequently restored with prefabricated zirconia crowns. On permanent teeth, these restorations may need to be removed and replaced with permanent restorations.

Objectives. To explore and compare the use of 2 high-powered erbium lasers for removing prefabricated zirconia crowns from molar teeth as a non-invasive alternative to rotary instruments.

Material and methods. Twenty-five permanent molars were prepared to dentin and prefabricated all-ceramic zirconia crowns were fitted and cemented with resin modified glass ionomer (RMGI) cement. The teeth were randomly assigned into one of the 2 retrieval treatment groups: the erbium-doped yttrium, aluminum and garnet (Er:YAG) laser group (G1; n = 12) or the erbium, chromium-doped yttrium, scandium, gallium and garnet laser (Er,Cr:YSGG) laser group (G2; n = 13). The laser operating parameters for the Er:YAG laser were 300 mJ, 15 Hz, 4.5 W, and 50-microsecond pulse duration (SSP mode); for the Er,Cr:YSGG laser, they were 4.5 W, 15 Hz, 20 water/20 air, and 5 W, 15 Hz, 50 water/50 air, and 60-microsecond pulse duration (H mode). The experiment was repeated twice. The surface area and the volume of teeth and crowns were measured and the cement space was calculated. The retrieval time and temperature changes were tested and recorded. The data were analyzed with the t-test. The surfaces of the dentin and the crown from each group were further examined using scanning electron microscopy (SEM).

Results. The average time for crown removal using the Er:YAG laser was 1 min 32.7 s; for the Er,Cr:YSGG laser it was 3 min 13.9 s ($p < 0.0001$). The mean temperature changes were $1.41 \pm 1.36^\circ\text{C}$ for the Er:YAG laser and $2.2 \pm 0.99^\circ\text{C}$ for the Er,Cr:YSGG laser ($p = 0.0321$). The SEM examination showed no damage or major structural changes caused by treatment with either erbium-family laser.

Conclusions. Both lasers are effective, non-invasive tools to remove prefabricated zirconia crowns cemented with resin cement and should be considered as viable alternatives to rotary instrumentation.

Key words: debonding, erbium laser, glass ionomer, prefabricated crown, zirconia

Introduction

Prefabricated crowns are a commonly used, predictable restorative option indicated for severely decayed or damaged teeth in the pediatric population. The goal of using them is to restore masticatory function, preserve healthy tooth structure, facilitate oral hygiene, and offer a durable, cost-effective treatment outcome.¹ With the development of biomaterials and an increased desire for esthetic outcomes, tooth-colored restorations, such as monolithic ceramic crowns, are gradually replacing traditional stainless steel crowns. Zirconia is a biocompatible, high-strength, wear-resistant, and color-stable material combining function and esthetics.¹ In the case of secondary caries, endodontic interventions and demand for a permanent restoration, it can be challenging and unpleasant for a pediatric dental patient to have these high-strength, all-ceramic materials removed using rotary instruments.

Recent studies have demonstrated a predictable way of retrieving ceramic restorations using erbium lasers: an erbium, chromium-doped yttrium, scandium, gallium and garnet laser (Er,Cr:YSGG), or an erbium-doped yttrium, aluminum and garnet laser (Er:YAG). They have emission wavelengths of 2780 nm and 2940 nm, respectively, which correlates with the peak absorption range of water.^{2–4} This results in good absorption into biological tissues and materials containing water, making them suitable for ablation, vaporization, disinfection,^{5–8} treatment of caries and osseous tissue,^{9–11} and other beneficial biological effects.^{9,12} The use of erbium lasers has also been explored in the removal of translucent restorations such as composite restorations, fiber-reinforced composite posts,¹³ veneers,^{14,15} brackets,¹⁶ and ceramic crowns.^{5,17–20} The light emitted by erbium lasers is transmitted through the translucent ceramic materials and is selectively absorbed by water molecules and residual monomers in the resin and glass ionomer cements. This absorption results in the vaporization of the molecules and ablation of the cement and hydrodynamic ejection.^{17,20} The mechanism of action for laser ablation in hard tissue or cement is based on rapid subsurface expansion. The volume of water trapped within the mineral substrate or cement is expanded and causes micro-explosions of the surrounding material or tissue.²¹ Heat generation is inevitable and has to be considered to prevent thermal injury of the pulpal tissues.²² Temperature changes during laser irradiation should remain within a tolerable range so as not to affect the vitality of the pulp and surrounding tissues.

The time required to remove lithium disilicate crowns with high-speed burs is approx. 6 min, while laser-assisted removal is estimated to take 60–90 s.²⁰ Using an Er:YAG laser for crown removal has been shown to be an effective and safe method; however, the parameters have not yet been optimized and iatrogenic damage has been reported in the literature when using higher laser settings.^{20,23,24} Recent studies have suggested that an Er:YAG laser presents

an effective, efficient method for removing lithium disilicate and zirconia crowns from implant abutments without causing damage to either or significantly increasing the temperature in the process.^{17,18} Similar studies have been performed on human teeth using an Er,Cr:YSGG laser, reporting acceptable temperature changes and effective zirconia and lithium disilicate crown removal.⁵ Both Er:YAG and Er,Cr:YSGG lasers have been shown to be effective and safe, although differences do exist in absorption and ablation efficiency between the 2 erbium lasers. The Er:YAG laser has been shown to be more efficient in enamel and in dentin due to a higher absorption compared to the Er,Cr:YSGG laser.^{23–28} Closer study of the absorption peak between the 2 lasers shows three-fold higher absorption coefficients for the Er:YAG laser over the Er,Cr:YSGG one. Consequently, the heat generated by the Er,Cr:YSGG laser has more time to spread deeper into the irradiated tissue or material, resulting in a thicker indirectly heated zone, which thermally affects the tooth or surrounding tissues more. This undesirable heating causes a waste of energy, resulting in reduced ablation efficiency²⁵ and more charring compared to the Er:YAG laser.²⁷

The aim of this *in vitro* study was to assess and compare the time of laser irradiation required to retrieve the cemented prefabricated zirconia crowns, and to assess the temperature changes during irradiation with Er:YAG and Er,Cr:YSGG pulsed lasers using similar operating parameters. An additional aim was to evaluate whether the length of laser irradiation required to debond the crown is related to the abutment or crown surface area.

Material and methods

In this research, we complied with the World Medical Association (WMA) Declaration of Helsinki and the Code of Medical Ethics of Virginia Commonwealth University (VCU).

Twenty five permanent molars were stored in saline after extraction.²⁹ The teeth were evaluated for the amount of remaining non-carious tooth structure and were excluded from the study if they presented with fractured crowns, gross caries or previous restorations.

All teeth were prepared following the manufacturer's instructions with 1–2 mm of occlusal reduction and 20–30% overall clinical crown reduction. The preparation was slightly tapered with a chamfer and feather-edge margin to ensure the passive fit of the selected prefabricated zirconia crowns (NuSmile, Houston, USA). All teeth were numbered and the prepared surfaces were scanned with an intraoral scanner (Planmeca Emerald; Planmeca, Helsinki, Finland) (Fig. 1A). All prefabricated zirconia crowns were air-dried and cemented using BioCem Universal Active Cement resin modified glass ionomer (RMGI) cement (BioCem; NuSmile) according to the manufacturer's instructions. The crowns were carefully seated and stabilized with finger

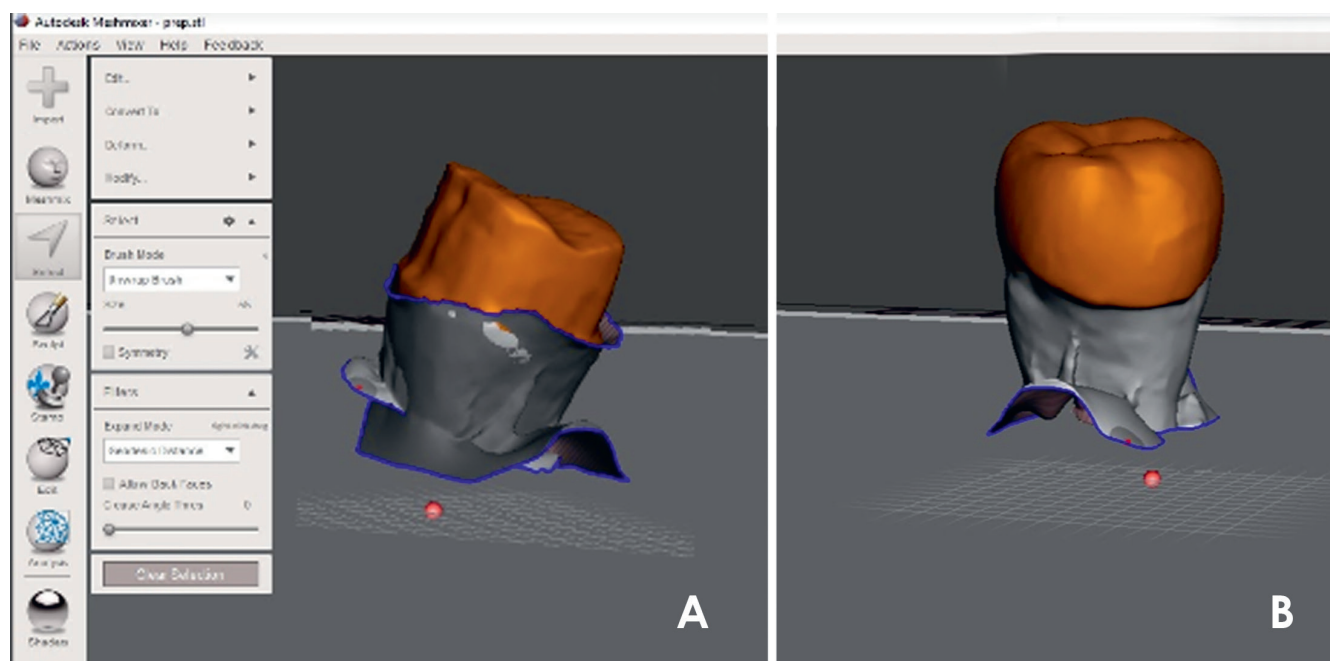


Fig. 1. Prepared surfaces of teeth (A) and cameo surfaces of the crowns (B) were scanned to calculate tooth surface area and the tooth volume

pressure for approx. 20 s. The cement was polymerized for 5–10 s with a curing light (800–1200 mW/cm²) on both the facial and lingual sites. After gently removing any excess cement, the crowns were polymerized for an additional 20 s on the facial, lingual and occlusal surfaces, mimicking the clinical situation where interproximal sites are not accessible. All the teeth were stored in a humidior for 24–48 h before retrieval was initiated. Following cementation, a 2nd scan of each tooth with a cemented crown was made. All stereolithographic files (STL format) were imported into Meshmixer® software (MeshMixer®; Autodesk, San Rafael, USA) in order to calculate the prepared tooth surface area [mm²] and cement volume [mm³]. Both scans were superimposed and sectioned at the marginal line of the crown to determine the exact margin of the bonding surface area on the prepared teeth. The volume of the bonded tooth preparation and the overall volume of the tooth, cement and crown were measured. The cement volume was then calculated from the difference between the overall volume and sum of the volumes of bonded tooth preparation and prefabricated crown. The prefabricated crown volumes were provided by the manufacturer (Fig. 1B).

The teeth were divided into 2 groups according to the laser used for the debonding procedure.

Group 1 (G1): debonding with Er:YAG laser (LightWalker; Fotona, Ljubljana, Slovenia). The 1st debonding experiment was labeled G1-FL1 (n = 12) and the 2nd debonding experiment was labeled G1-FL2 (n = 10).

Group 2 (G2): debonding with Er,Cr:YSGG laser (Waterlase; Biolase, Irvine, USA). The 1st debonding experiment was labeled G2-BL1 (n = 13) and the 2nd debonding experiment was labeled G2-BL2 (n = 13).

Each crown was debonded twice to determine whether the previous laser debonding process would affect adhesion properties or shorten the time needed to retrieve the crowns.

The laser settings in this study were chosen based on reports from previous studies, manufacturers' recommendations and our observations. The goal was to achieve minimal retrieval time at the lowest possible settings to avoid potentially harmful temperature increases and irreversible damage to the tooth substance. The laser irradiation was combined with light tapping forces and digital manipulation of the crowns for their retrieval.

Experiment 1

The settings used for the Er:YAG laser were the same for both experiments (G1-FL1 or G1-FL2) and were based on our observations from previous studies.^{17,18} The operating parameters of the laser were 300 mJ, 15 Hz, 4.5 W, and 50-microsecond pulse duration (super-short pulse (SSP) mode) with the non-contact H02 tip. The settings for the Er,Cr:YSGG laser were closely matched in the 1st experiment (G2-BL1): 4.5 W, 15 Hz, 20 water/20 air, and 60-microsecond pulse duration with the Turbo MX9 handpiece.

After the 1st debonding, the crowns were cleaned according to the manufacturer's recommendations and checked for cracks and damage. The remaining cement and debris was removed from the tooth using a dental air polishing and the crowns were re-cemented using the same cement and cementation procedure. All teeth were stored in a humidior for 24–48 h before the 2nd retrieval.

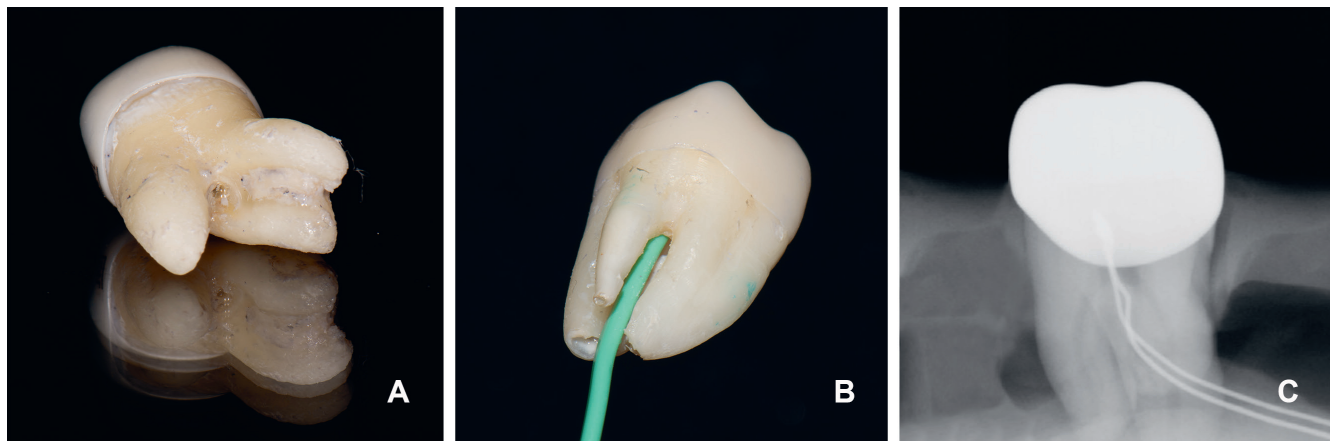


Fig. 2. To measure temperature changes inside the tooth during the laser irradiation, a channel was prepared through the furcation (A) to enable insertion of the temperature probe (B) into the pulp chamber (C)

Experiment 2

The 2nd experiment was repeated using the same laser parameters for the Er:YAG laser (G1-FL2). Slight modifications were made to the Er,Cr:YSGG laser settings based on the manufacturer's recommendations: 5 W, 15 Hz and 50 water/50 air with the Turbo MX9 handpiece (G2-BL2).

Laser debonding procedure

The crowns were irradiated in a continuous motion of the handpiece on the buccal, occlusal and lingual surfaces, including the crown margins in a back-and-forth motion 2–5 mm from the crown surface for 30 s. The proximal surfaces were not irradiated in order to mimic adjacent teeth being present in the mouth. To test whether the crown could be removed, it was manipulated with digital palpation and a crown tapping instrument applied to the buccal and lingual margins. If the crown could not be successfully removed, additional 30-second intervals of irradiation and tapping followed. These intervals were repeated until the crown could be successfully retrieved.

Surface evaluation

After debonding, each crown and tooth were examined visually and under a microscope using $\times 40$ magnification (Leica M320; Leica Microsystems, Wetzlar, Germany) to analyze the adherence of the cement and any damage to the tooth or the intaglio surface of the crown. The surfaces of the sample teeth and crowns were further examined under a scanning electron microscope (SEM) (JEOL 6610LV; JEOL, Tokyo, Japan) in order to examine the structural integrity and any possible surface damage to the crown and tooth caused by the laser irradiation. The specimens were treated using a low-vacuum mode with an energy range of 20 kV and they were not coated.

Pulpal temperature

Following crown cementation, a channel (3–4 mm in diameter) was drilled through the furcation into the pulpal chamber of each tooth to facilitate the insertion of a microthermal couple probe (Adv. Thermocouple Therm. with RS 232 Output Datalogger Type K-800008; Super Scientific Works Pvt. Ltd., Vadodara, India) into the pulpal chamber (Fig. 2). Before initiating laser irradiation, baseline pulpal temperatures were recorded. The temperature in the pulpal chamber was recorded every 30 s.

Statistical analysis

The data was analyzed using equal and unequal variance *t*-tests, as appropriate. Associations between crown metrics (inner and outer surface area and spacer volume) were assessed using Pearson's correlation coefficient. The significance level was set at 0.05. SAS EG v. 6.1 software (SAS Institute, Cary, USA) was used for all of the analyses.

Results

Er:YAG laser

The average time for crown removal using the Er:YAG laser in group 1 was 1 min 33.8 s (standard deviation (SD) = 16.8 s) for the 1st experiment (G1-FL1) and 1 min 31.5 s (SD = 16.5 s) for the 2nd experiment (G1-FL2). There was no statistically significant difference between the 2 groups ($p = 0.6480$).

The irradiation time required to debond the crown was positively correlated with the spacer volume ($r = 0.67$; $p = 0.0007$). Debonding time was not significantly associated with inner ($r = -0.21$; $p = 0.34$) or outer ($r = -0.14$; $p = 0.55$) surface area. Table 1 includes correlations for the study groups.

Table 1. Pearson's correlation coefficients for associations between crown metrics and irradiation time

Type of laser	Group	Outer surface area	Inner surface area	Space volume
Er:YAG	G1-F1 (n = 12)	−0.154	−0.241	0.758*
	G1-F2 (n = 10)	−0.113	−0.176	0.545**
	overall	−0.136	−0.211	0.667*
Er,Cr:YSGG	G2-BL1 (n = 13)	0.506**	0.586*	0.539**
	G2-BL2 (n = 13)	0.711*	0.801*	0.123
	overall	0.515*	0.586*	0.287

* $p < 0.05$; ** $0.05 < p < 0.10$; Er:YAG – erbium-doped yttrium, aluminum and garnet laser; Er,Cr:YSGG – erbium, chromium-doped yttrium, scandium, gallium and garnet laser.

Table 2. Average temperature changes by group [°C]

Type of laser	Group	n	Mean	SD
Er:YAG	G1-F1 (n = 12)	12	1.7	1.62
	G1-F2 (n = 10)	10	1.0	0.92
	overall change	22	1.4	1.36
Er,Cr:YSGG	G2-BL1 (n = 13)	13	2.2	0.80
	G2-BL2 (n = 13)	13	2.1	1.19
	overall change	26	2.2	0.99

SD – standard deviation; Er:YAG – erbium-doped yttrium, aluminum and garnet laser; Er,Cr:YSGG – erbium, chromium-doped yttrium, scandium, gallium and garnet laser.

Er,Cr:YSGG laser

The average time for crown removal using the Er,Cr:YSGG laser in group 2 was 2 min 34.7 s (SD = 67.9 s) for the 1st experiment (G2-BL1) and 3 min 53.1 s (SD = 63.8 s) for the 2nd experiment (G2-BL2), which indicated a statistically significant difference between the 2 groups ($p = 0.0058$).

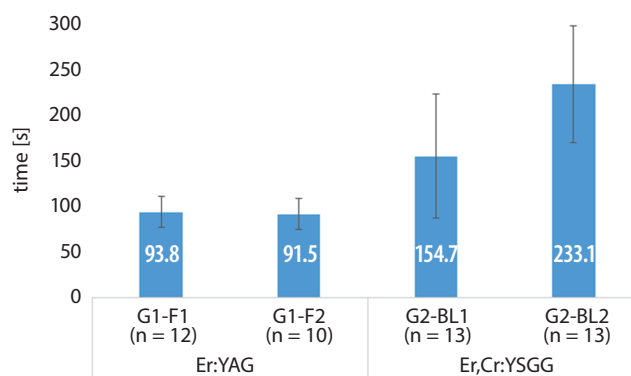
The irradiation time required to debond the crown was positively correlated with both outer surface area ($r = 0.52$; $p = 0.01$) and inner surface area ($r = 0.59$; $p = 0.002$). Irradiation was not significantly correlated with spacer volume ($r = 0.29$; $p = 0.16$). Table 1 includes correlations for the study groups.

Comparison: Er:YAG vs Er,Cr:YSGG

The 1st debonding was, on average, 60.9 s faster (standard error (SE) = 20.2) for the Er:YAG laser than for the Er,Cr:YSGG laser, which was a statistically significant difference ($p = 0.0076$). For the 2nd debonding, the Er:YAG laser was 2 min 21.6 s faster, on average, than the Er,Cr:YSGG laser, which was also statistically significant ($p < 0.0001$) (Fig. 3).

Pulpal temperature

The mean temperature changes were $1.40 \pm 1.36^\circ\text{C}$ for the Er:YAG laser and $2.2 \pm 0.99^\circ\text{C}$ for the Er,Cr:YSGG laser ($p = 0.0321$). For both erbium lasers, the differences in temperature change between the 2 debonds were not statistically significant ($p = 0.23$ and 0.76 , respectively).

**Fig. 3.** Debond time for both experiments for Er:YAG and Er,Cr:YSGG lasers

All pulpal temperatures remained within a safe range, with the highest recorded temperature change of 5°C for Er:YAG and 4°C for Er,Cr:YSGG. These temperatures should be interpreted with caution, as they reflect various other factors such as the temperatures of the room and water. The temperature range during the irradiation is shown in Table 2.

Scanning electron microscopy analysis

After irradiation, none of the teeth or crowns appeared damaged on visual inspection or under an optical microscope using a $\times 40$ magnification lens.

The SEM examination did not reveal any damages or major structural changes suggesting photoablation or thermal ablation of the abutment teeth caused by irradiation of either laser (Fig. 4). The decrease in adhesion strength

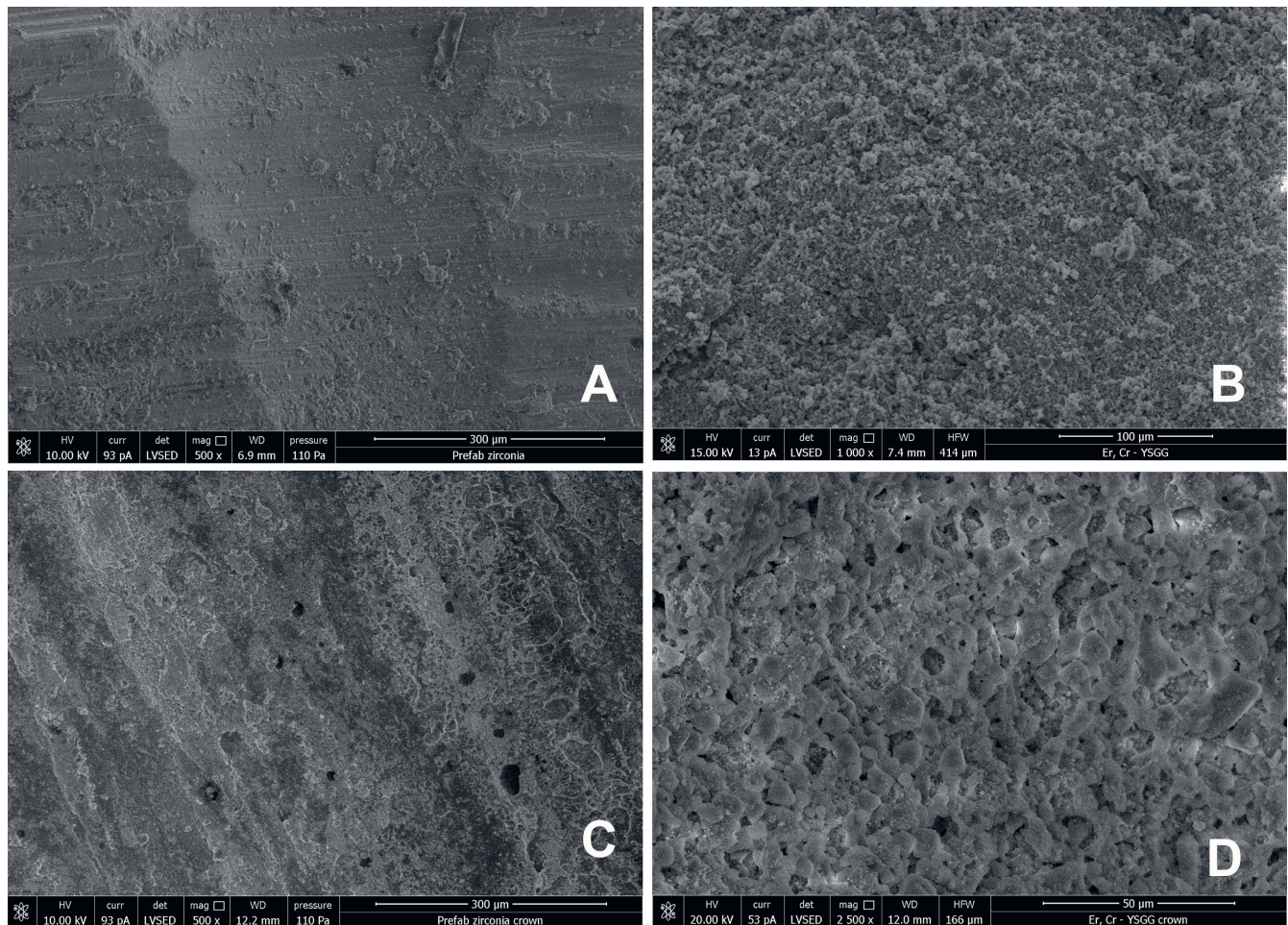


Fig. 4. Residual cement and undamaged surface is observed on SEM images of the teeth following irradiation with Er:YAG laser (A) and Er,Cr:YSGG laser (B) and intaglio surface of the crowns following Er:YAG (C) and Er,Cr:YSGG laser (D) laser

appeared either between the cement and the tooth surface, leaving the cement attached mostly inside the crown, or between the cement and the intaglio surface of the crown, leaving cement attached to the surface of the tooth. No carbonization, cracks or fractures in the macro- or micro-structure were observed on the tooth or on the zirconia prefabricated crown. Slight, partial ablation of the cement caused by Er,Cr:YSGG laser irradiation was occasionally observed. The intaglio surfaces appeared to be similar in roughness for both lasers. The teeth treated with the Er:YAG laser showed less cement remaining on the surfaces than those treated with the Er,Cr:YSGG laser (Fig. 4).

Discussion

The development of prefabricated all-ceramic crowns and modern adhesive systems has improved the restorative options for severely damaged teeth in the pediatric and adolescent population. The removal of these temporary restorations can be challenging and is usually accomplished with rotary instruments. Alternatively, atraumatic removal can be predictably and reproducibly accomplished

using high-powered erbium lasers such as Er:YAG and Er,Cr:YSGG.³⁰ Both erbium lasers are selectively absorbed by water molecules²⁵ and residual monomers of cements, leading to a decrease in adhesion strength between the cement and the crown or a tooth due to photothermal ablation. A dentin–crown interface can be debonded with thermal softening, thermal ablation or photoablation, resulting in cracks in the cement layer and the breakage of material bonds.^{5,17,20}

Closer study of the absorption peak between the 2 lasers shows three-fold higher absorption coefficients for the Er:YAG laser in comparison to the Er,Cr:YSGG laser. The Er,Cr:YSGG laser wavelength thus penetrates deeper into the tissue and requires more time to heat up the irradiated volume to the evaporation temperature, while the substance heated by the Er:YAG laser will reach ablation temperatures faster and progress deeper into the targeted substance.^{25,31} Our findings are in alignment with these observations, since the time required to debond the crowns was shorter for the Er:YAG laser than the Er,Cr:YSGG laser after the 1st debonding using similar settings. Both lasers showed clinically acceptable debonding times, proving them to be an efficient tool for crown debonding.

Heat generated by an Er,Cr:YSGG laser has more time to spread deeper into the tissue, resulting in a thicker indirectly-heated zone exerting greater thermal effects on the tooth. This undesirable heating of the surrounding tissue is also the reason energy is lost, resulting in less efficient ablation.²⁴ To prevent thermal injury of the pulpal tissues, heat generation and accumulation should be minimal. An increase in pulpal temperature of 5.5°C can cause irreversible damage to the pulp tissue³²; a rise in temperature of 10°C for 60 s on the root surfaces can cause irreversible damage to the periodontal ligament and bone that can lead to bone resorption and tooth ankylosis.^{33,34} In this study, temperature changes measured in the pulpal chamber throughout the irradiation were minimal and did not exceed critical temperature changes. No significant temperature increase was observed, even when the slightly higher settings for Er,Cr:YSGG were used in the 2nd experiment.

Both lasers provide continuous water cooling that was in this study effective in regulating temperature during irradiation. Only temperature changes during laser irradiation in relation to the baseline temperature were reported. The initial temperatures were not standardized for all experiments and differed slightly due to variations in room temperature on different days.

The key factors of successful debonding include technique, the duration of laser irradiation, fluency, an adequate

pulse of the mid-infrared wavelength, and continuous, uninterrupted irradiation.³⁵ The working parameters for both lasers used in this study were low and safe, yet provided efficient and reproducible debonding of the restorations.

Laser-assisted ceramic crown removal encompasses several factors that may affect its efficiency: the chemical composition and type of ceramic material, the thickness of the restoration, the type, shade and thickness of the resin cement, the shade and opacity of the ceramic material, and the parameters of the laser (power, pulse duration, frequency, and irradiation time).^{15,36–39} The advantage of retrieving a crown with an erbium laser is to preserve the crown for re-cementation. In this study, all the crowns were re-cemented after the 1st debonding and tested again. The results of this study indirectly showed a predictable bond strength after re-cementation of the crowns as the debonding time did not decrease during the 2nd irradiation; it even increased for the 2nd Er,Cr:YSGG laser group. The slightly higher power (0.5 W) used for the 2nd debonding (G2-BL2) should theoretically result in a shorter irradiation time but resulted in significantly increased debonding time. One possible explanation could be the use of a 50% water spray, causing higher absorption of the laser on the wet surface of the crown, therefore lowering the energy efficiency in the cement layer. Another possible explanation could be a lighter tapping force employed by a different

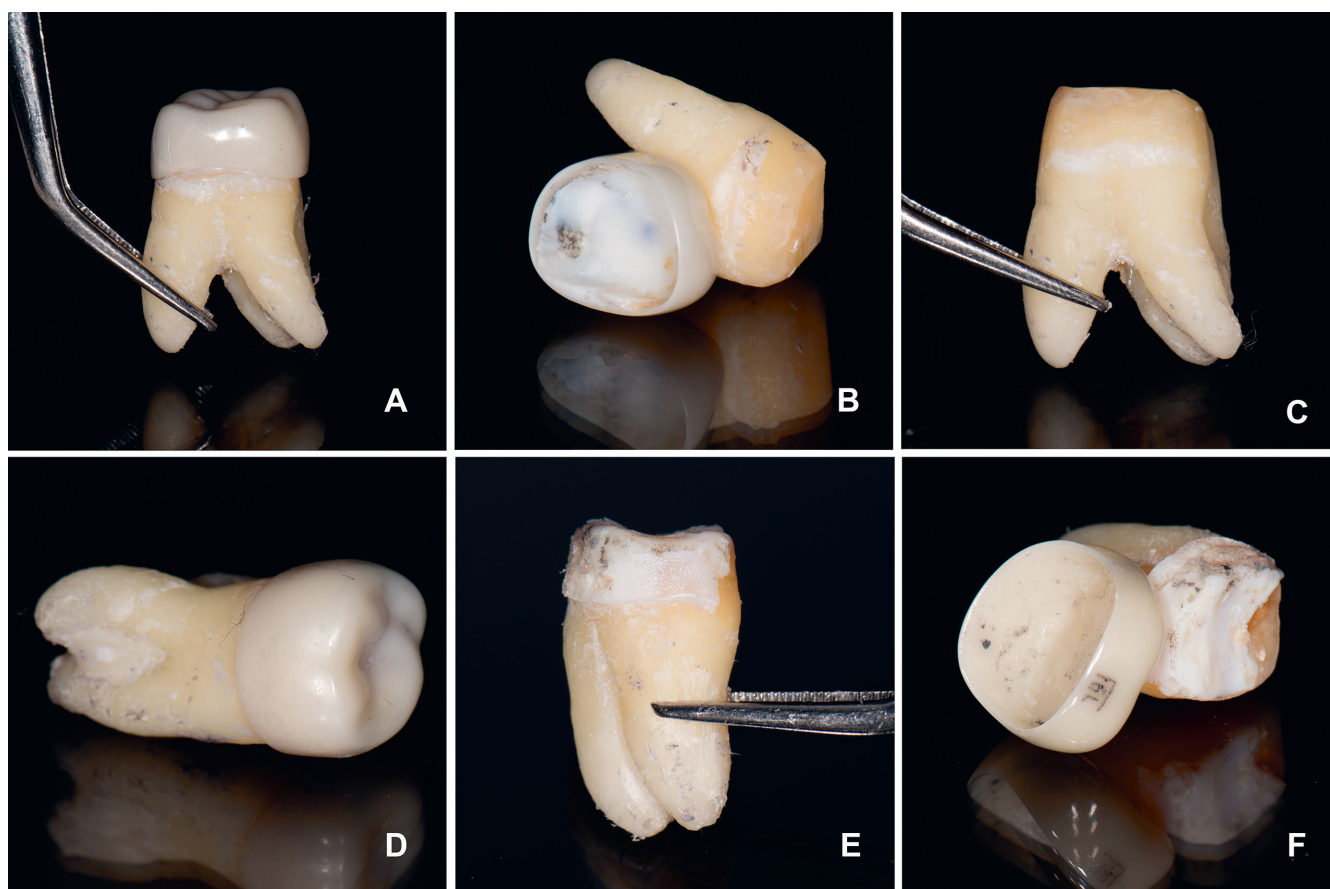


Fig. 5. Following erbium laser irradiation, debonding of the crown resulted in either retention of the cement attached to the intaglio surface of the crown (A–C) or the surface of the tooth (D–F)

operator. This could be an important additional finding, as in many clinical scenarios, the use of tapping instruments with a considerable force may not be feasible. This is also true for younger and more sensitive patients, where parents may object and there is a risk of iatrogenic damage to the tooth and crown. A short burst of additional laser irradiation could therefore be used to minimize or avoid using any kind of tapping instrument, allowing for digital retrieval of the crown from the tooth.

Interestingly, debonding occurred either between the cement and tooth, with the cement remaining inside the crown, or between the cement and inner surface of the crown, with the cement remaining on the tooth surface. The Er,Cr:YSGG laser group, with a longer irradiation time, was associated with less residual cement on the tooth and more residual cement inside the crown. In contrast, most of the remaining cement in the Er:YAG laser group was retained on the tooth surface (Fig. 5).

The laser settings and debonding procedure resulted in minimal structural changes to the crown and tooth surface according to macro- and microscopic examination. No crowns or teeth were fractured or broken during the experiments. Since no thermal effects were exerted by either laser, it can be concluded that this treatment modality with either of the 2 lasers provides safe, efficient and predictable removal of the crown and does not affect future re-cementation.

During the experiment, we encountered some limitations. The force used to tap the crowns off the teeth greatly depends on the clinician and was not measured or standardized in our experiment. With a stronger tapping force, the debonding time was consistently shorter, whereas with the use of a very light tapping force or only digital manipulation, the time required to retrieve the crown increased.

Conclusions

The removal of cemented all-ceramic crowns with the use of an Er:YAG or Er,Cr:YSGG laser is a viable alternative to rotary techniques. Laser-assisted prefabricated zirconia crown debonding is atraumatic, time-efficient, predictable, and reversible with erbium-family lasers.

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