



Er:YAG laser lithium disilicate crown removal: removal time and pulpal temperature change

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Abstract

Since the removal of resin-luted all-ceramic restorations is a challenge, the use of Er:YAG lasers has become popular. The aim of this study was to determine the removal time of monolithic lithium disilicate crowns in different thicknesses and heat transmission to pulp using Er:YAG laser. Forty-five full-coverage monolithic lithium disilicate crowns in 1 mm ($n = 15$), 1.5 mm ($n = 15$), and mixed thickness ($n = 15$) were resin luted on relevant extracted human maxillary first premolars and subjected to Er:YAG laser irradiation for crown removal after 24 h. Laser parameters for each thickness, respectively, were 5 W, 5.6 W, and 5.9 W (10 Hz). The removal time and temperature change values were recorded for each sample. The statistical evaluations were performed using one-way ANOVA variance and post hoc Duncan and Tamhane's T2 tests ($p < 0.05$), and Pearson correlation coefficient was used to examine the significance within each group and without group discrimination. All crowns were laser-debonded successfully. The removal time (min:s) at the succeeding laser parameter for each group is as follows: between 2:30 and 4:45 at 5 W power for 1-mm samples, between 5:00 and 11:15 at 5.9 W power for 1.5-mm samples, and between 8:45 and 15:00 at 5.9 W power for samples in mixed thickness. Moreover, it was observed that the temperature changes in the pulp chamber did not exceed the critical value of 5.5 °C for any sample. Er:YAG laser irradiation is an effective and safe method for removal of all-ceramic crowns when appropriate laser parameters are used according to thickness.

Keywords All-ceramic · Ceramic thickness · Debonding · Heat transmission · Laser parameter

Introduction

Although porcelain-fused-to-metal restorations are widely used in cases that require prosthetic rehabilitation, they cannot meet esthetic expectations owing to the opaque porcelain and metal framework used underneath. Therefore, all-ceramic materials are increasingly preferred for esthetics owing to their high light transmittance ability [1]. In the cementation process of all-ceramic restorations, both tooth-resin cement interface and ceramic-resin cement interface should be considered. The aim of successful cementation is to firmly bond all-ceramic material to the tooth surface. A high bond strength is achieved in all-ceramic materials thanks to resin-luting cements [2]. Although this is seen as

an advantage in all-ceramic restorations, it is a disadvantage in cases where the restoration needs to be removed for any reason, such as ceramic fracture, discoloration, marginal misfit, endodontic treatment needs, improper placement of the restoration, or esthetic complaints [3, 4].

Manual or automatic crown removers and burs are frequently used in all-ceramic crown removal processes. However, this method has disadvantages such as patient discomfort and damage to the restoration and dental tissues [5]. Therefore, new alternatives to the traditional crown removal methods have been developed. Lasers, which are used in many areas of dentistry, have also been used for the removal of resin-bonded dental applications such as orthodontic ceramic brackets [6–11], laminate veneers [12–15], and full-coverage all-ceramic restorations [16–19].

Er:YAG lasers (2940 nm) are the most effective and safe laser type for all-ceramic restoration removal because of their high absorption capability in hard tissues and resin cements, including water [5]. Debonding occurs by the degradation of resin cement via different mechanisms, such as

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thermal softening, thermal ablation, and photoablation [20]. Thermal softening, which is a relatively slow method, causes a large temperature rise in tooth structures. Thermal ablation heats up the resin instantly and provides rapid vaporization of the resin cement owing to laser energy. Laser energy is absorbed by OH ions in the resin cement and may debond the bonded restoration by creating an expansion of the resin. Photoablation occurs with a high laser energy, which increases the energy levels of the bond between the resin atoms above their dissociation levels. Er:YAG laser debonding of all-ceramic restorations is mostly based on “thermal ablation” and “photoablation” mechanisms [21].

The heat released after laser irradiation is dangerous to the target tissue. To preserve tooth vitality, the amount of heat transmitted to the pulp should be kept under control. The increased levels of heat transmitted during laser irradiation may cause irreversible changes in the pulp, periodontal ligament, and supporting bone. A temperature increase in the pulp of more than 5.5 °C, which is the critical limit, may cause loss of vitality [22]. Necrotic changes may be observed in 16.7 °C temperature increase in dental pulp [17]. It is important not to exceed these critical values in vital teeth during laser debonding.

The type of bonded tooth surface, ceramic type, thickness of the restoration, and restoration type, whether it is a laminate veneer or full-coverage restoration, affect the decision of sufficient laser parameter selection. There is a considerable number of studies on bracket and laminate veneer debonding with an Er:YAG laser [6–15]; however, there is a limited number of studies on full-coverage all-ceramic crown debonding [16–19]. Moreover, no study has been published evaluating the removal time and pulpal temperature change of all-ceramic crowns in different thicknesses. Therefore, the aim of this study was (i) to determine the removal time of resin-bonded all-ceramic crowns in different thicknesses using an Er:YAG laser and (ii) to determine the heat transmission values to the pulp during laser irradiation. The null hypotheses for this study were as follows: (i) there would be an increase in removal time directly proportional to crown thickness and (ii) a decrease in pulpal temperature change inversely proportional to crown thickness.

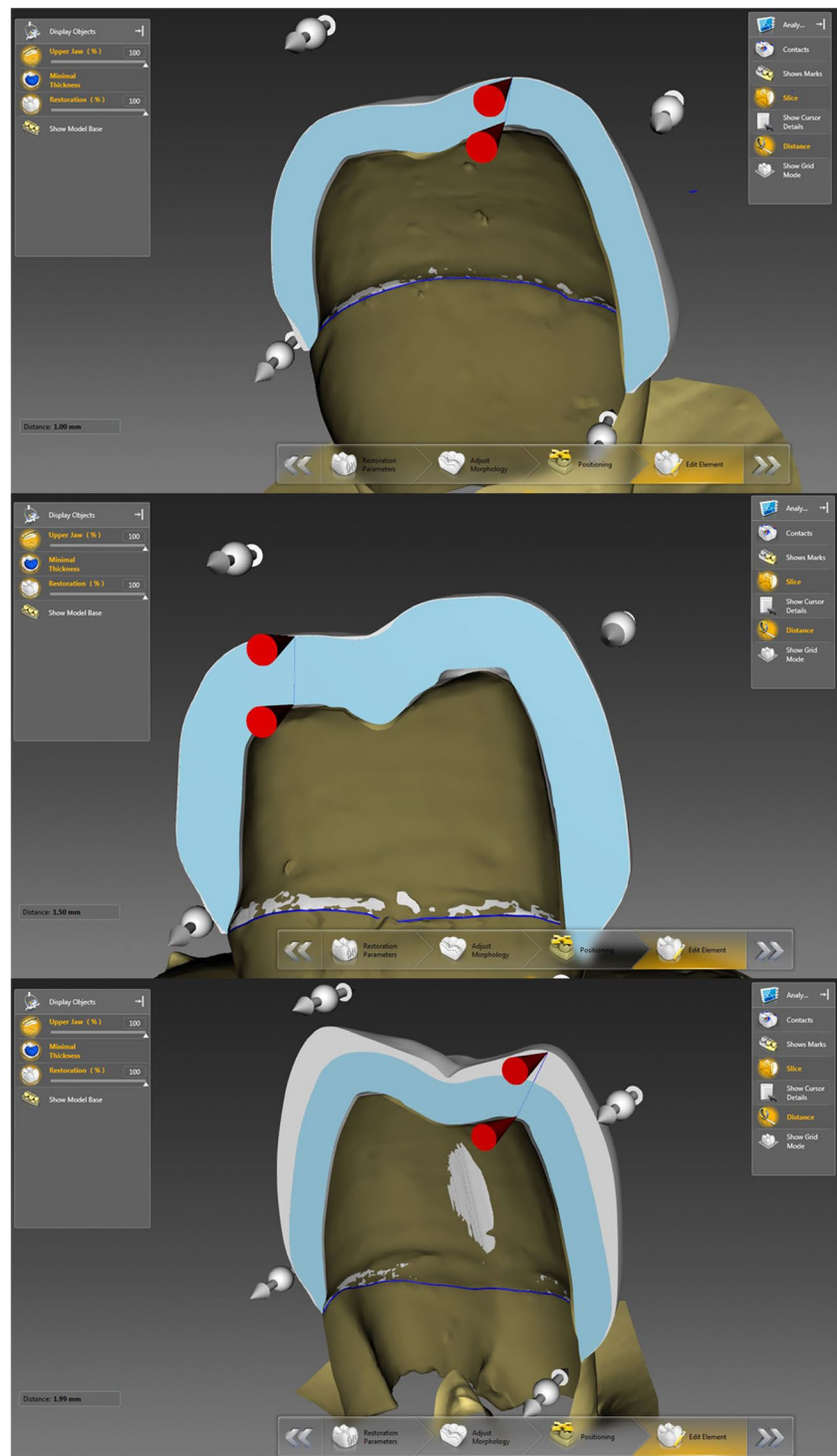
Materials and methods

Forty-five intact human maxillary premolars, which were extracted for orthodontic and periodontal reasons, were used. Dental calculus and periodontal tissues on the enamel and cementum were removed using an ultrasonic scaler (Lm-Ergo Grip Ultra; Lm Dental, Parainen, Finland) and polished with a polishing paste (Prophy Paste; Sultan Chemist Inc., York, USA). After decontamination with a 0.1% thymol solution for 24 h, the teeth were stored in distilled water

until use [23]. Before tooth reduction, the roots were covered with a thin layer of melted modeling wax and embedded in self-curing acrylic resin blocks for fixation. The reductions were made by using a conical-shaped chamfer bur (Ökodent Gruppe, Tautenhain, Thüringen, Germany) with a high-speed handpiece fixed on a surveyor (KaVo EWL Typ 990; KaVo Elektrotechnisches Werk GmbH, Leutkirch im Allgäu, Germany). The sizes (height, length, and diameter) of all prepared tooth samples were made similar to each other as much as possible. The prepared tooth surfaces were scanned using an inEos X5 device (Dentsply Sirona Charlotte, NC 28277, USA). After scanning, crown designs were made using the inLab 18.1 (Dentsply Sirona Charlotte, NC 28277, USA) program. Monolithic lithium disilicate all-ceramic material (IPS E.max CAD, MT, A1; Ivoclar Vivadent, Schaan, Liechtenstein) was used to fabricate samples of three groups in different thicknesses ($n = 15$). The thickness of the samples was designed 1 mm for the 1st group, 1.5 mm for the 2nd group at all surfaces, and in mixed thickness between 1 and 2 mm (marginal 1/3: 1 mm, middle 1/3: 1.5 mm, and occlusal 1/3: 2 mm) that was existing in the inLab 18.1 design program (Dentsply Sirona Charlotte, NC 28277, USA) for the 3rd group (Fig. 1). An inLab MC X5 fabrication device (Dentsply Sirona Charlotte, NC 28277, USA) was used to fabricate the samples as a maxillary first premolar. After fitting the unsintered monolithic lithium disilicate crowns on to the relevant prepared teeth, the crystallization process was performed in a firing furnace (Programat P310; Ivoclar Vivadent, Liechtenstein).

During cementation of the crowns to relevant tooth samples, the prepared tooth samples were etched with 37% orthophosphoric acid gel (Total Etch, Ivoclar Vivadent, Liechtenstein) for 15 s, then washed, and dried. After the etching process, a universal adhesive (Adhese Universal; Ivoclar Vivadent, Liechtenstein) was applied using a brush for 20 s according to the manufacturer’s instructions. After 20 s of air-spray application to dilute the adhesive material, it was light-cured for 10 s. The inner surfaces of the crowns were acid-etched with 5% hydrofluoric acid (IPS Ceramic Etching Gel; Ivoclar Vivadent, Liechtenstein) for 20 s and then washed and dried with an air-water spray for 30 s. Silane (Monobond S; Ivoclar Vivadent, Liechtenstein) was applied to the etched ceramic surfaces for 60 s. After the surface treatment, the crowns were cemented to prepared tooth samples using a dual-cure system (Variolink Esthetic DC; Ivoclar Vivadent, Liechtenstein). Dual-cure resin luting cement was applied directly to the crown with an application tip, and the crown was placed on the tooth. After the excess cement had been removed, the samples were light-cured for 20 s on each surface respectively, buccal, palatal, mesial, distal, and occlusal. Cementation procedures for each group were performed on different days. After the cementation process was completed, the

Fig. 1 Designing the thickness of the samples in the inLab 18.1 program for each thickness group



samples were kept in distilled water at 37 °C in an incubator for 24 h. Each specimen was embedded in silicone, with its mesial and distal surfaces in contact with the artificial tooth. The crown removal process was performed using a solid-state Er:YAG laser (Fidelis III; Fotona d.o.o, Ljubljana, Slovenia), which is a 7-mirror articulated arm device (Fig. 2).

Since there is no study on “which laser parameter is adequate for different thicknesses,” a preliminary study was initially performed.

The laser application parameters were obtained for each thickness based on the data obtained in the preliminary study. The laser parameters, which varied according to the crown thickness, were as follows. For crowns with a



Fig. 2 Er:YAG laser irradiation of resin luted samples, aligned between the artificial tooth

thickness of 1 mm, the laser parameters were set at a power of 5.0 W (frequency, 10 Hz; pulse energy, 500 mJ; peak power, 5000 W; total energy, 50 J) with a wavelength of 2940 nm and pulse duration of 100 μ s (VSP mode). For crowns in 1.5 mm and mixed thicknesses, the laser parameters were set at a power of 5.9 W (frequency, 10 Hz; pulse energy, 590 mJ; peak power, 5900 W; total energy, 59 J) with a wavelength of 2940 nm and a pulse duration of 100 μ s (VSP mode). The non-contact mode (focused mode) handpiece (R02), which had 0.9 mm spot diameter and spot area of 0.0064 cm² at the crown surface, was used at a distance of 7–8 mm. Irradiation was performed at 2/2 water/air cooling ratio (14 ml/min) (Table 1).

Laser was applied using a scanning method in a zigzag pattern, starting from the buccal surface. The laser was applied up and down from the occlusal margins to the cervical margins for 30 s. The same application pattern was used for the palatal surface for 30 s. After the buccal and palatal surfaces, the laser was applied to the buccal and palatal line angles/cusps for 30 s, 15 s for buccal line angles/cusps, and 15 s for palatal line angles/cusps. Irradiation was then applied to the occlusal surface. The occlusal surface was irradiated from contact point to contact point for 30 s. Finally, the laser was applied to the interproximal areas from both the lingual and buccal sides for 30 s totally. The total laser application period was 2 min 30 s for the first laser application. The application was repeated after crown removal was tested and was not successful. The subsequent application durations were reduced to half the initial duration (1 min 15 s) at each application surface. Laser application was continued until the crown was removed.

Heat transmission values were measured in the pulp chamber during laser application using a micro-thermocouple testing device (CEM DT-613 Dual-Channel

Table 1 Er:YAG laser properties and parameters tested in the study

Er:YAG laser application	
Laser type	Solid state
Wavelength	2940 nm
Delivery system	7-mirror articulated arm
Water/air cooling	2/2 (14 ml/min)
Hand piece type	R02 (non-contact)
Application method	Scanning technique (zigzag movement)
Pulse energy	500 mJ ^a , 590 mJ ^b
Pulse width	100 μ s
Total energy	50 J ^a , 59 J ^b
Frequency	10 Hz ^{a,b}
Average power	5 W ^a , 5.9 W ^b
Peak power	5000 W ^a , 5900 W ^b
Spot diameter	0.9 mm
Spot area at ceramic surface	0.0064 cm ²
Average power density	781.2 W/cm ^{2a} , 921.9 W/cm ^{2b}
Energy density/fluence	78.1 J/cm ^{2a} , 92.2 J/cm ^{2b}

Laser parameters with the same superscript letters are in same application scenarios

Thermocouple; Inkatech, Adana, Turkey). The maximum, minimum, and average temperatures observed during the laser application period were automatically recorded using a micro-thermocouple. To measure temperature changes in the pulp chamber, a hole was drilled on the root surface with a round bur (Model 801 014 C FG; Ökodent Gruppe, Tautenhain, Thuringia, Germany). The remaining pulp tissue was removed, the pulp chamber was filled with thermally conductive silicone paste (Concord Thermal Grease; Concord, Gaziantep, Turkey), and a micro-thermocouple tip was placed into the pulp chamber. Radiographs were used to confirm the correct tip position (Fig. 3). Crown removal was attempted after each laser application period. Attempts at crown removal were made using a Heidemann spatula, and the crown was scratched off from the gingival margin.

The removal time of the all-ceramic crowns, initial temperature before laser application, and the minimum, maximum, and average values during laser application were recorded for each sample. All statistical analyses were performed using IBM SPSS V23 package program (Chicago, IL, USA). In addition to calculating the mean value and standard deviation, the sample distribution of the data was assessed using the Shapiro-Wilk test. One-way ANOVA was used to analyze the normally distributed debonding time (s) and temperature change ($^{\circ}$ C) values. Post hoc multiple comparisons were performed using Duncan and Tamhane's T2 tests at a significance level of 0.05, and the Pearson correlation coefficient was used to examine the significance between debonding time (s) and temperature change ($^{\circ}$ C) parameters within each group and without group discrimination.

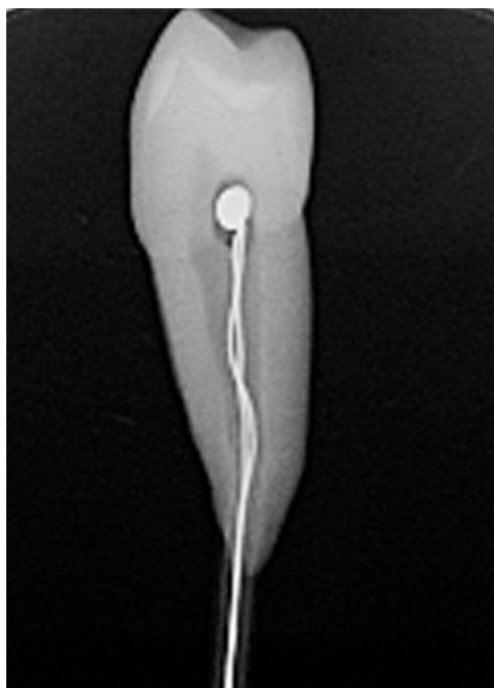


Fig. 3 Radiographic view of the micro-thermocouple type K probe placed in the pulp chamber

Results

All resin-bonded monolithic lithium disilicate crowns in different thicknesses were laser-debonded using the appropriate parameters determined in our previous pilot study. Except for two samples, the remaining samples were removed in one piece. It was observed that the temperature changes in the pulp chamber did not exceed the critical value of 5.5 °C for any sample.

Monolithic lithium disilicate crowns in 1 mm thickness (1st group) were laser irradiated and removed with a power of 5.0 W (frequency 10 Hz, pulse energy 500 mJ) between 2:30 and 4:45 (min:s) time period. The maximum temperature change was 5.4 °C during laser irradiation. The crowns in the 2nd group were laser irradiated and removed with a power of 5.9 W (frequency 10 Hz, pulse energy 590 mJ) between 5:00 and 11:15 (min:s). The maximum temperature change was 5.0 °C during laser irradiation. The monolithic

lithium disilicate crowns in mixed thickness (3rd group) were laser irradiated and removed with a power of 5.9 W (frequency 10 Hz, pulse energy 590 mJ) between 8:45 and 15:00 (min:s) and a maximum temperature change of 4.6 °C.

There were statistically significant differences in debonding time between the groups ($p < 0.001$). The debonding time mean values and respective standard deviations of each group were 201 ± 42.73 s for the 1st group, 485 ± 123.13 s for the 2nd group, and 680 ± 118.47 s for the 3rd group. A statistically significant difference was found between the mean temperature change values ($p = 0.026$). A significant difference was between the 1st and 3rd groups which had mean value of 4.11 and 3.41 °C, respectively (Table 2).

There was no statistically significant correlation between the debonding time and temperature change values for each group ($p > 0.05$). Regardless of the group, there was a statistically significant negative correlation between debonding time and temperature change values ($r = -0.469$; $p = 0.001$) (Table 3).

Discussion

Although all-ceramic restorations provide excellent esthetics with high light transmittance, the removal procedure is difficult because of the high bond strength provided by the resin cement in cases where removal is required for any reason [5]. It is virtually impossible to remove lithium disilicate crowns cemented with resin cement in one piece using current crown removal methods. This difficulty in removing lithium disilicate restorations has led researchers to seek new methods, including lasers, which have been used in many areas of dentistry. In a limited number

Table 3 Correlation between debonding time and temperature change for each group and regardless of groups

	<i>r</i>	<i>p</i>
1 mm thickness	- 0.398	> 0.05
1.5 mm thickness	- 0.362	> 0.05
Mixed thickness	- 0.223	> 0.05
Regardless of groups	- 0.469	< 0.001

“*r*” Pearson correlation coefficient

Table 2 Statistical significance of debonding time (s) and temperature change (°C) values in each group

	1 mm thickness Mean ± SD	1.5 mm thickness Mean ± SD	Mixed thickness Mean ± SD	<i>p</i>
Debonding time (s)	201 ± 42.73 ^a	485 ± 123.13 ^b	680 ± 118.47 ^c	< 0.001
Temperature change (°C)	4.11 ± 0.79 ^a	3.65 ± 0.6 ^{ab}	3.41 ± 0.67 ^b	< 0.05

The same superscript letters indicate no statistically significant difference between groups ($p > 0.05$)
SD standard deviation

of previous studies where the Er:YAG laser was used for crown removal, the crown thicknesses were not evaluated [16–19]; however, it is known that the thickness affects the laser light transmittance [13]. It is therefore important to address this issue. While it is aimed at removing the crown with an Er:YAG laser, preserving tissue vitality is another important issue. It is critical that the temperature change in the pulp during the laser debonding process does not exceed 5.5 °C [17, 22]. The aims of this study were to determine the removal time of resin-bonded all-ceramic crowns in different thicknesses using an Er:YAG laser and to determine the heat transmission values to the pulp during laser irradiation. Based on the results, the increase in removal time directly proportional to crown thickness failed to reject the first null hypothesis, and the decrease in pulpal temperature change inversely proportional to crown thickness was not able to reject the second null hypothesis as it had been presented because there was a significant difference between the 1st and 3rd groups ($p = 0.026$).

In the study of Cifuentes et al. [13], it was concluded that laser irradiation influenced the debonding of veneers in different thicknesses: easier debonding was observed in thinner veneers tested on disc samples. Debonding of an all-ceramic crown was examined by 2 studies of Rechmann et al. [16, 17], in which the crown samples were in standard thickness of 1 to 2 mm: 1.5 mm at contact points, 1.5 mm at non-functional cusps, 2.0 mm at functional cusps, and 1 mm at margins. In the study of Gurney et al. [19], the lithium disilicate specimens of 1.5 mm in thickness were tested with different laser parameters to determine the optimum parameters for crown removal. However, the thickness of full-coverage all-ceramic restorations can range from 1 to 2 mm, and the application of a laser to debond crowns in different thicknesses has not yet been reported. In our preliminary pilot study, crowns in 1, 1.5, and mixed thicknesses were tested to determine the appropriate laser irradiation power for each. In the current study, all-ceramic crowns in three different thicknesses were tested using the appropriate laser parameters determined according to the thicknesses in the pilot study.

In all-ceramic laminate veneer laser debonding studies, extracted human incisors or premolars were used as the sample bases [12–15, 23]. In the all-ceramic crown debonding studies of Rechmann et al., extracted human molars were used as samples [16, 17]. Since the all-ceramic crown restorations are especially applied in the esthetic zone [24], the samples were designed as maxillary first premolars instead of molars in the current study.

The laser parameters in the current study were 500, 560, and 590 mJ per pulse with a 10-Hz pulse repetition rate, which were determined according to the results of our preliminary study. The preliminary study was aimed at finding out the most appropriate laser parameter for

each thickness, with efficient removal in safe pulpal heat transmission.

The debonding time and pulpal temperature change may be affected by the water/air (W/A) cooling ratio and pulse duration (PD) [14]. Albalkhi and Hamadah [14] investigated the laser debonding of laminate veneers and tested different W/A cooling ratios and PD parameters. It was concluded that a W/A cooling ratio of 2/2 and PD values of 50 or 100 μ s were efficient, fast, and safe for the removal of lithium disilicate veneers. Using W/A cooling ratios of 3/3 and 1/1 resulted in the longest debonding time and the highest increase in the pulp temperature, respectively [14]. In the current study, a 100- μ s PD with a 2/2 cooling ratio was used to keep the tooth safe accompanied by efficient crown debonding.

Zhang et al. [15] performed a laser application using a scanning method on the entire laminate surface horizontally and vertically. Rechmann et al. used a similar method on crowns, starting from the occlusal surface and moving onto the line angles of the buccal and lingual cusps and the buccal, lingual, and proximal surfaces [16]. In the present study, the laser application started from the buccal surface, followed by the palatal and proximal surfaces. The laser was applied to the line angles, to cusps, and finally to occlusal surfaces. Irradiation was initiated from the axial and proximal surfaces instead of the occlusal surface, as the ablation at the occlusal surface initially accompanied by strict retention at the other surfaces could cause a ceramic fracture at the occlusal area.

Removal of all-ceramic restorations after laser application without any intervention has rarely been reported in the literature. Although the resin bond weakens after laser irradiation, a push/pull force may be necessary when using different types of tools, which have been used in previous studies. Walinski et al. [12] reported that the remaining resin was weakened in the powdery state and could be easily removed using hand instruments and gauze. In the study of Rechmann et al. [16], a dislodging force was applied in the occlusal direction to separate the crown from the tooth with a slight pulling force using a plier, placed on the buccal and lingual surfaces of the crown. In the present study, after laser irradiation at the planned time, a Heidemann spatula was placed on the cervical margin and removed with a slight push. The Heidemann spatula is more reliable than a plier because it does not damage the crown or tooth [25].

Full-coverage all-ceramic crown removal using an Er:YAG laser has not been reported sufficiently in the literature. Rechmann et al. [16] reported that the irradiation time until debonding of lithium disilicate crowns in mixed thickness varied from 85 to 420 s without any fracture at pulse energy values between 304 and 590 mJ with a 10-Hz repetition rate. In the other study of Rechmann et al. [17], it was found that the debonding time of the samples was

between 85 and 210 s at a fixed laser parameter of 560-mJ pulse energy and 10-Hz repetition rate. Both studies were performed using extracted human molars. In the current study, tooth-supported monolithic lithium disilicate crowns in different thicknesses were laser irradiated and successfully removed in different time periods such as; 1-mm-thickness crowns at 500-mJ pulse energy, 10-Hz repetition rate between 150 and 210 s; 1.5-mm-thickness crowns at 590-mJ pulse energy, 10-Hz repetition rate between 300 and 675 s; mixed-thickness crowns at 590-mJ pulse energy, 10-Hz repetition rate between 525 and 900 s. The debonding time periods in the current study were higher than those in the studies of Rechmann et al. [16, 17], because the premolar crown samples in the current study had a higher crown height/width ratio than molars, which increased crown retention. The composition of the crown affects the laser transmission and the removal time consequently. The layered lithium disilicate crown, which was not tested in this study, might be different in removal time. Rechmann et al. [16] discussed the probability of laser removal time difference of layered all-ceramic crowns vs monolithic ones and assumed that the layered ones might be easy to remove.

A temperature increase in the pulp above 5.5 °C is already known as the critical value for the pulp that may cause irreversible pulpal damage [17, 22]. Rechmann et al. [17] reported that the average temperature rise of 20 all-ceramic crowns was 5.4 ± 2.2 °C during laser debonding. The temperature change was between 1.6 and 11.5 °C and exceeded the 5.5 °C critical value eight times. This can be explained by the way that they used their water cooling. They reported that the temperature rises greater than critical value occurred when the water was applied to the opposite side of the laser irradiation side [17]. In the present study, it was observed that the average and minimum-maximum temperature changes seen during laser application were 4.11 ± 0.79 °C and 2.6–5.4 °C for crowns in 1 mm thickness, 3.65 ± 0.6 °C and 2.8–4.5 °C for crowns in 1.5 mm thickness, and 3.41 ± 0.67 °C and 2.1–4.6 °C for crowns in mixed thickness. It was found that the temperature rise was inversely proportional to crown thickness as hypothesized at the beginning of the study. None of the samples exceeded the critical temperature rise of 5.5 °C under a constant air/water cooling ratio of 2/2, which was applied from the tip of the laser handpiece to the same direction with the irradiation.

The limitations of this study are that only one resin cement was used and lithium disilicate crowns in only one shade were tested. Rechmann et al. [26] stated that when testing the ablation thresholds of different resin cements, differences in the energy values were needed to start fuming of the cement ablation. According to the results of their studies, while some cements needed roughly 4.4–4.7 J/cm² for ablation, one started ablating at approximately

44% less energy. A study on the effect of crown material shade on crown removal using an Er:YAG laser has not yet been published. It can be assumed that the material shade may affect the laser light transmittance, and studies can be carried out on this subject. Only one shade type (MT A1) was tested in the present study. Another limitation of the study was that the layered lithium disilicate, which might be different from the monolithic type in removal time, was not tested in this study. An additional limitation may be that the possible cooling effects of blood circulation were not considered when examining pulpal temperature rise in vitro without simulating pulpal blood flow [27, 28].

Conclusion

Er:YAG laser irradiation is an efficient method for the removal of all-ceramic restorations. This study indicated that the Er:YAG laser is effective in removing monolithic lithium disilicate crowns up to 2 mm in thickness and the restorations are not damaged during the removal procedure. In addition, this study determined that the energy transmitted to the pulp during full-contour crown removal does not cause a dangerous temperature change in the pulp if the laser application is performed under appropriate air-water cooling. The increase in the thickness of the monolithic lithium disilicate crown was directly proportional to the debonding time and inversely proportional to the pulpal temperature rise. Consequently, using an Er:YAG laser for debonding resin-bonded monolithic lithium disilicate crowns could be an effective and safe clinical application when used with appropriate parameters for the related thickness.

Author contribution Gozneli Rifat: conceptualization, methodology, validation, formal analysis, investigation, resources, writing, review, editing, visualization, supervision, and project administration.

Sendurur Tansu: validation, formal analysis, investigation, resources, data curation, and writing original draft.

Declarations

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors. This article only contains a study with test samples prepared by using extracted human maxillary premolars that were previously extracted for periodontal reasons. Although no human participants or animals were performed, this study was approved by the university human research ethics committee and all procedures performed in studies (involving human participants) were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Competing interests The authors declare no conflict of interest.

References

- McLean JW (2001) Evolution of dental ceramics in the twentieth century. *J Prosthet Dent* 85:61–66. <https://doi.org/10.1067/mpr.2001.112545>
- Stewart GP, Jain P, Hodges J (2002) Shear bond strength of resin cements to both ceramic and dentin. *J Prosthet Dent* 88:277–284. <https://doi.org/10.1067/mpr.2002.128034>
- Oztoprak MO, 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 Med Sci* 27:713–716. <https://doi.org/10.1007/s10103-011-0959-1>
- Van As G (2013) Using the erbium laser to remove porcelain veneers in 60 seconds. *J Cosmet Dent* 28:20–34
- Kellesarian SV, Malignaggi VR, Aldosary KM (2017) Laser assisted removal of all ceramic fixed dental prostheses: a comprehensive review. *J Esthet Restor Dent* 30:216–222. <https://doi.org/10.1111/jerd.12360>
- Yilanci H, Yildirim ZB, Ramoglu SI (2017) Intrapulpal Temperature Increase During Er:YAG Laser-Aided Debonding of Ceramic Brackets. *Photomed Laser Surg* 35:217–222. <https://doi.org/10.1089/pho.2016.4198>
- Nalbantgil D, Tozlu M, Oztoprak MO (2014) Pulpal thermal changes following Er-YAG laser debonding of ceramic brackets. *ScientificWorldJournal* 2014:912429. <https://doi.org/10.1155/2014/912429>
- Mirhashemi AH, Hossaini SMH, Etemadi A, Kharazifard MJ, Bahador A, Soudi A (2019) Effect of Er:YAG and Er,Cr:YSGG lasers on ceramic bracket debonding from composite blocks. *Front Dent* 16:88–95. <https://doi.org/10.18502/fid.v16i2.1359>
- Mocuta DE, Miron MI, Lungeanu D, Mateas M, Ogodescu E, Todea CD (2022) Laser Er:YAG-Assisted debonding may be a viable alternative to the conventional method for monocrytalline ceramic brackets. *Int J Environ Res Public Health* 19:14564. <https://doi.org/10.3390/ijerph192114564>
- Grzech-Leśniak K, Matys J, Żmuda-Stawowiak D, Mroczka K, Dominiak M, Brugnera Junior A, Gruber R, Romanos GE, Sculean A (2018) Er:YAG laser for metal and ceramic bracket debonding: An in vitro study on intrapulpal temperature, SEM, and EDS analysis. *Photomed Laser Surg* 36:595–600. <https://doi.org/10.1089/pho.2017.4412>
- Downarowicz P, Noszczyk P, Mikulewicz M, Nowak R (2020) Thermal effect of Er:YAG and Er,Cr:YSGG used for debonding ceramic and metal orthodontic brackets: An experimental analysis. *Adv Clin Exp Med* 29:557–563. <https://doi.org/10.17219/acem/118844>
- Walinski CJ, Gibson JE, Colvert DS, Redmond DC, Jafarian JH, Gregory PN, Ou KL (2021) Debonding of leucite-reinforced glass-ceramic veneers using Er, Cr:YSGG laser device: Optimizing speed with thermal safety. *Oper Dent* 46:100–106. <https://doi.org/10.2341/18-005-L>
- Cifuentes HG, Gómez JC, Guerrero ANL, Muñoz J (2020) Effect of an Er,Cr:YSGG laser on the debonding of lithium disilicate veneers with four different thicknesses. *J Lasers Med Sci* 11:464–468. <https://doi.org/10.34172/jlms.2020.72>
- AlBalkhi M, Hamadah O (2022) Influence of pulse duration and water/air cooling ratio on the efficiency of Er:YAG 2940 nm laser in debonding of porcelain laminate veneers: An in vitro study. *Clin Exp Dent Res* 8:843–848. <https://doi.org/10.1002/cre2.554>
- Zhang Y, Rocca JP, Fornaini C, Zhen Y, Zhao Z, Merigo E (2018) Erbium-doped, yttrium-aluminum-garnet laser debonding of porcelain laminate veneers: An ex vivo study. *Contemp Clin Dent* 9:570–573. https://doi.org/10.4103/ccd.ccd_632_18
- Rechmann P, Buu NCH, Rechmann BMT, Finzen FC (2014) Laser all-ceramic crown removal—a laboratory proof-of-principle study—phase 2 crown debonding time. *Lasers Surg Med* 46:636–643. <https://doi.org/10.1002/lsm.22280>
- Rechmann P, Buu NCH, Rechmann BMT, Finzen FC (2015) Laser all-ceramic crown removal and pulpal temperature—a laboratory proof-of-principle study. *Lasers Med Sci* 30:2087–2093. <https://doi.org/10.1007/s10103-015-1738-1>
- Deeb JG, Bencharit S, Dalal N, Abdulmajeed A, Grzech-Leśniak K (2019) Using Er:YAG laser to remove lithium disilicate crowns from zirconia implant abutments: An in vitro study. *PLoS One* 14:e0223924. <https://doi.org/10.1371/journal.pone.0223924>
- Gurney ML, Sharples SD, Phillips WB, Lee DJ (2016) Using an Er,Cr:YSGG laser to remove lithium disilicate restorations: A pilot study. *J Prosthet Dent* 115:90–94. <https://doi.org/10.1016/j.prosdent.2015.08.003>
- Tocchio RM, Williams PT, Mayer FJ, Standing KG (1993) Laser debonding of ceramic orthodontic brackets. *Am J Orthod Dentofac Orthop* 103:155–162. [https://doi.org/10.1016/S0889-5406\(05\)81765-2](https://doi.org/10.1016/S0889-5406(05)81765-2)
- Morford CK, Buu NC, Rechmann BM, Finzen FC, Sharma AB, Rechmann P (2011) Er:YAG laser debonding of porcelain veneers. *Lasers Surg Med* 43:965–974. <https://doi.org/10.1002/lsm.21144>
- Matsumoto K (2000) Lasers in Endodontics. *Dent Clin N Am* 44:889–907
- Karagoz-Yildirak M, Gozneli R (2020) Evaluation of rebonding strengths of leucite and lithium disilicate veneers debonded with an Er:YAG laser. *Lasers Med Sci* 35:853–860. <https://doi.org/10.1007/s10103-019-02872-8>
- Barwacz CA, Hernandez M, Husemann RH (2014) Minimally invasive preparation and design of a cantilevered, all-ceramic, resin-bonded, fixed partial denture in the esthetic zone: a case report and descriptive review. *J Esthet Restor Dent* 26(5):314–323. <https://doi.org/10.1111/jerd.12086>
- Bishara SE, Ostby AW, Laffoon J, Warren JJ (2008) Enamel cracks and ceramic bracket failure during debonding in vitro. *Angle Orthod* 78(6):1078–1083. <https://doi.org/10.2319/112007-540.1>
- Rechmann P, Buu NC, Rechmann BM, Le CQ, Finzen FC, Featherstone JD (2014) Laser all-ceramic crown removal—a laboratory proof-of-principle study—phase 1 material characteristics. *Lasers Surg Med* 46(8):628–635. <https://doi.org/10.1002/lsm.22279>
- Raab WH (1992) Temperature related changes in pulpal microcirculation. *Proc Finn Dent Soc* 88:469–479
- Kodonas K, Gogos C, Tziafas D (2009) Effect of simulated pulpal microcirculation on intrapulpal temperature changes following application of heat on tooth surfaces. *Int Endod J* 42:247–252. <https://doi.org/10.1111/j.1365-2591.2008.01508.x>

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