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EXPLORING THE USE OF PULSED ERBIUM LASERS TO RETRIEVE A ZIRCONIA CROWN FROM A ZIRCONIA IMPLANT ABUTMENT

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EXPLORING THE USE OF PULSED ERBIUM LASERS TO RETRIEVE A ZIRCONIA CROWN FROM A ZIRCONIA IMPLANT ABUTMENT

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science at Virginia Commonwealth University.

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Abstract

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Removal of zirconia crowns, commonly used as cement-retained implant fixed restorations, can be challenging. Conventional methods of crown removal are time consuming and often leave irreparable damage to the crown, which can be costly to patients and practitioners. This research explored the use of two different types of pulsed erbium lasers, erbium-doped yttrium aluminum garnet laser (Er:YAG) and erbium, chromium-doped yttrium, scandium, gallium and garnet (Er,Cr:YSGG), as non-invasive tools to retrieve cemented zirconia crowns from zirconia implant abutments. Times needed to remove the crowns were recorded and analyzed using ANOVA (α=0.05). No statistical differences between the debond times of each laser were observed. The surfaces of the crown and the abutment were further examined using scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDS) examination. SEM and EDS examinations of the materials showed no visual surface damaging or material alteration from the two pulsed erbium lasers.

Key Words: Crown Removal; Dental Lasers; Er:YAG; Er,Cr:YSGG; Implant Crowns; Zirconia Crowns; Zirconia Abutments

CHAPTER 1

INTRODUCTION

Partial edentulism, referring to a condition of missing teeth, is one of the most common human diseases. Just in the United States alone, more than 178 million Americans are missing at least one tooth.[1] Amongst many dental treatments for partial edentulism, dental implant treatment remains to be a reliable and long lasting solution. When properly executed, a dental implant has close to 98% success rate.[2]

A discussion of basic dental implant therapy and procedures will provide a core understanding of terminologies and biomaterials that forms an essential foundation knowledge for this research. Dental implant therapy replaces a missing tooth by placing a titanium screw known as an implant fixture into the patient's jawbone, maxillary or mandibular alveolar bone. A dental implant fixture is a hollow titanium screw functioning as a replacement of a natural root of a missing tooth. The implant fixture functions as a support for the overlying dental prosthesis. After the implant fixture is surgically placed, the osseointegration process usually takes approximately 4 to 6 months after implant surgical insertion. This means that the implant has successfully integrated into the patient's jaw bone, alveolar bone. After the implant is osseointegrated, an abutment, a prosthesis-retaining screw is screwed into the implant. Finally, a dental prosthesis, in this case a crown, is inserted onto the abutment that connects it with the dental implant.

Abutments are the point of connection between the overlying crown and the underlying implant. The abutment is typically held in place by being screwed onto the implant. On the other hand, an implant crowns can either be screw-retained or cement-retained onto the abutment or screwed into the implant fixture. Screw-retained crowns represent a simple design that provides a quick and easy way to secure the crown in place.[3–5] However, using screw-retained crowns in areas of the mouth where the angulation and oral architecture does not allow for easy access to the screw access channel can be challenging. Therefore, the use of cement-retained crowns is often unavoidable in such areas, such as the anterior esthetic zone of the mouth. Cement-retained crowns are simply held onto their abutment following cement application and after allowing the cement to polymerize and solidify.

Recent emphasis on esthetics has played a major role in almost all dental treatments including types of materials used for implant crown. Restorative dentistry, where esthetics and function go hand in hand, is not an exception. Restorative materials that are functionally durable and long lasting while still esthetically pleasing are therefore in high demand. Zirconia restorative materials have become one of the most commonly used materials in restorative dentistry with its excellent physical and biological properties and recent short-term clinical evidence [6–9] Furthermore, zirconia abutments and crowns are often a treatment of choice for a single-tooth implant in the esthetic zone.[10–13]

Despite the many advantages of zirconia crowns, they do come with their own set of challenges. Long term maintenance of a patient's prosthesis especially implant prostheses can encompass many dental treatments, some of which require the removal of the cemented crowns off their fitting abutments.[7,14] Zirconia is considered to be relatively the strongest ceramic material currently available. Cement-retained zirconia implant crowns are therefore difficult to remove using conventional methods. Rotary handpieces with cutting diamond burs often have a difficult time cutting through zirconia crowns. This conventional method not only takes a considerable amount of time, but also leaves the zirconia crown un-reusable. Often, the burs would also damage the zirconia abutment.[15,16]

The introduction of laser use in the dental field has gone through multiple phases. Lasers were first introduced for the purposes of soft tissue surgeries, such as soft tissue removal and recontouring [17]. Later, laser use encompassed some hard tissue procedures and treatments[18], such as caries removal and composite resin removal [19]. Recently, lasers are being used for purposes of dental prosthesis removal, such as the removal of veneers[20], crowns, and orthodontic brackets. Erbium lasers are a specific category of lasers that have become well established in the field of dentistry over the years. The most two common types of erbium lasers used are the Er:YAG and Er,Cr:YSGG lasers. Both lasers use solid state crystals, YAG or YSGG, doped with erbium ions (Er^{3+}) as their active materials [21]. Moreover, both lasers are pumped by a pulsed broadband flashlamp. However, the two lasers have different types of pulse mechanism technology utilized to energize the flashlamps. Er,Cr:YSGG uses an older technology, Pulse Forming Network (PFN). Er:YAG uses a newer technology, Variable Square Pulse (VSP) [22]. The Er:YAG VSP technology allows for pulse duration adjustability, which offers better control over ablation efficiency. Both lasers generally work similarly, their wavelengths fall in mid-infrared range (2940 nm - 2790 nm) exhibiting the highest absorption for water and hydroxyapatite molecules as their target chromophores [23]. However, it might be worth noting that the Er:YAG wavelength (2940 nm) falls directly on the maximum water absorption spectrum of water when compared to the Er,Cr:YSGG wavelength (2790 nm). Moreover, water absorbs the lasers' energy turning into steam, releasing that energy in the form of "mini explosions" that are responsible for the lasers' ablating capabilities [24,25]. On the other hand, the subtle but important differences in the lasers' wavelengths and in range of available pulse duration, can have an effect on the optimal laser condition where high ablation and minimal heat deposition in teeth are preferred. Such differences also contribute to the laser's capabilities in controlling the balance between attaining the highest possible tissue ablation and the effects on the underlying tissue, in terms of tissue preservation and coagulation. With such differences taken in consideration it is therefore acknowledged that despite both lasers being able to perform the same job, Er:YAG lasers perform more optimally, especially in water, offering better control over thermal deposition and more precise control over the laser's effect on the underlying tissue. On the other hand, while Er,Cr:YSGG laser is less effective at ablation, it can penetrate deeper[21].

Pulsed erbium lasers are generally high-power lasers that can perform a wide range of functions. Those lasers can be used in skin resurfacing and soft tissue de-epithelialization,[26] ablative and non-ablative,[27] vaporizing soft tissue as means of bacterial control,[28–30] and in esthetic surgery such as selective removal of skin epidermis with accelerated healing and anti-scarring [28,31]. This study proposed that erbium pulsed lasers such as Er:YAG with 2940 nm wavelength and Er,Cr:YSGG with 2780 nm wavelength can be used to remove a zirconia crown off a zirconia implant abutment. The study expanded the applications from previous studies where lithium disilicate crowns were removed from titanium and zirconia implant abutments using an Er:YAG laser.[15,16] Theoretically, the wavelengths of these lasers operate with the mid-infrared spectrum, which coincides with the range for water absorption spectrum. Hence, water molecules and possibly the remaining monomer molecules in the cement are the target chromophore for these erbium pulsed lasers.[16,32–35] Selection of the proper chromophore that is in or near the laser's spectrum absorption target is essential for maximal efficiency. Different lasers emit different wavelengths; hence they target different chromophores. Hemoglobin for example is a different type of chromophore with an absorption spectrum around 1000 nm and is often targeted if the goal is soft tissue remodeling, therefore Nd:YAG laser with 1064 nm wavelength is perhaps most suitable for such applications.[36] Hydroxyapatite is another chromophore that can be targeted using pulsed erbium lasers, hence these lasers are used for treatment of hard tissue, such as treatment of dental caries, bone defects and bone decortication [37,38]. Beside the laser's wavelengths, other parameters such as power, frequency and cooling are crucial in optimal laser's efficiency [39]. Water and remaining monomer molecules trapped within the luting cement polymerized structure are the main target chromophore for the purpose of removing a crown. These molecules absorb the wavelength emitted from the laser, and release an energy that is destructive to cement polymerized structure.[15,16] This study utilized two types of pulsed erbium lasers, Er:YAG and Er,Cr:YSGG lasers to retrieve zirconia crowns from zirconia abutments.

Previous studies have proven the possible use of pulsed erbium family lasers such as erbium-doped yttrium aluminum garnet laser (Er:YAG) and erbium, chromium-doped yttrium, scandium, gallium and garnet (Er,Cr:YSGG) lasers to retrieve restorations made of different ceramic and composite resin materials from natural teeth [32–41] and various types of implant abutments.[15,16,42,43] Recent studies have proven the validity of using Er:YAG laser to remove lithium disilicate crowns from titanium and zirconia abutments.[15,16] These studies have also validated the safety of using lasers as an alternative method by noting that when used under controlled laser parameters, the temperature increase as a result of irradiation are much lower than the temperature levels that can be harmful to the surrounding tissue, or to the crown, abutment, or implant fixture.[15,16] However, the use of pulsed erbium lasers to remove cemented zirconia crowns off zirconia abutments is yet to be explored.

The study aimed to compare the two laser efficacies, in terms of crown removing times, under similar parameters. The performance of Er:YAG laser was also tested over a repeated cementation trial simulating clinical scenarios of reusing the crown via repetitive cementation. Inspections for surface damage following irradiations were performed through scanning electron microscopy (SEM) analysis. Material composition as a response to irradiation was also examined using energy-dispersive X-ray spectroscopy (EDS).

HYPOTHESIS

We expect that repeated cementation following irradiation from the same laser, such as Er:YAG, should yield the same crown removal times, given the fact that the laser parameters remained constant and the zirconia material's absence of micromechanical bonding with the cement. The crown removal times for the two pulsed erbium lasers, Er:YAG and Er,Cr:YSGG, should be similar, based on their similar wavelength spectrum and adjusted operating parameters. Lastly, surface structure and material composition should experience little to no changes following Er:YAG and Er,Cr:YSGG irradiation, upon examination with SEM and EDS.

.

MATERIALS AND METHODS

Specimen design and fabrication process was similar to previous studies [15,16]. A dental cast of a patient missing a mandibular left second premolar that was replaced with a single dental implant (4.5 mm platform Tapered Screw-Vent Implant, Zimmer Biomet) was used. A zirconia prefabricated implant abutment (Contour Abutment, Zimmer Biomet) was placed onto the study cast. The abutment and the cast, the opposing cast and the buccal interocclusal registration were scanned using an intraoral scanner (Emerald, Planmeca). These scans were then used to design a crown using Romexis version 5 software (Planmeca). The crown was designed to have approximately 1-2 mm thickness except in the crown margin which was about 0.5 mm thick. The design was then exported in the standard tessellation language (STL) format and zirconia crowns were fabricated using a milling machine (PrograMill PM7, Ivoclar Vivadent). Twenty identical zirconia monolithic crowns were milled using a monolithic disc (IPS e.max ZirCAD, MT Multi, Ivoclar Vivadent). The zirconia used in this study is a combination of 3 mol% yttria stabilized tetragonal zirconia polycrystal (3Y-TZP) and 5 mol% yttria stabilized tetragonal zirconia polycrystal (5Y-TZP).

The milled crowns were then sintered for 9 hours and 50 minutes per the manufacturer's recommendation using a sintering furnace (Programat S1 1600, Ivoclar Vivadent). The sintered crowns were air-abraded using 50 µm aluminum oxide particles. Then the crowns underwent characterization and staining process using the same furnace (Programat S1 1600, Ivoclar Vivadent). The glazed crowns were then again air-abraded with 50 µm aluminum oxide particles, and the excess glaze if any around the crown margin was removed and polished. The crowns were then tried on the abutment to determine the fitting.

The abutments were then installed onto the implant fixtures. A piece of polytetrafluoroethylene (PTFE, Teflon) tape was used to cover the screw access of the abutment. Prior to cementation, the primer (Monobond Plus, Ivoclar Vivadent) was applied to the intaglio surface of the crown and left on for 60 seconds before blow drying. The crowns were luted onto the abutments using self-adhesive resin cement (RelyX™ Unicem 2, 3M). Buccal, lingual, and occlusal surfaces of the crown were subjected to a 1-to-2 second period of light polymerization to facilitate removal of excess cement. The cemented crowns were left under finger pressure for 6 minutes for complete polymerization. The cemented crowns were kept for 24 hours in a 100% humidifying chamber prior to the crown removal experiment. A total of 20 crowns cemented on abutment-implant fixture specimens were made.

Two pulsed erbium lasers were used in this study, erbium-doped yttrium aluminum garnet laser (Er:YAG) with 2940 nm wavelength (LightWalker, Fotona), and erbium, chromium-doped yttrium (LightWalker AT / AT S, Fotona), scandium, gallium and garnet (Er,Cr:YSGG) with 2780 nm wavelength (Waterlase iPlus, Biolase). Er:YAG laser was set at: 300 mJ, 15Hz, 4.5 W, operation mode: SSP mode (50 μs pulse duration) 2 water/2 air, while Er,Cr:YSGG laser was set at: 4.5 W, 15 Hz, with operation mode: H (60 μs pulse duration), 20 water/20 air. The irradiation protocol was the same for both lasers, and similar to the protocol from the previous study[15,16].

The crown specimens were grouped relative to the type of laser used for the crown removal and the number of times they were recemented. Group 1 (G1) was comprised of 10 crowns that had undergone two successive crown removal trials with recementation via the Er:YAG laser, with subgroups Er1 (Er:YAG cementation & 1st irradiation) and Er2 (Er:YAG recementation & 2nd irradiation). Group 2 (G2) consisted of a different set of 10 new crowns that were cemented and irradiated once using the second laser, Er,Cr:YSGG laser. Note that an extra zirconia crown was made. This extra zirconia crown and an extra prefabricated zirconia abutment were used in the SEM/EDS analysis as control samples.

The cemented crown/abutment/implant were held using forceps from the bottom end of the implant **(Fig 1a)**. The lasers were oriented perpendicular to the crown surface using the non-contact method (~5-10 mm away from crown surface). The cooling air/water spray feature was used during the entire irradiation time. The irradiation was carried out through directing the laser axially onto all non-occlusal surfaces for 180 seconds while rotating the crown slowly, then 60 seconds onto the occlusal surface, then lastly 30 seconds irradiation of all crown surfaces. After the initial 240 seconds of irradiation, the crown's dislodgement was assessed through gentle tapping and pulling action. If the crown was not dislodged, subsequent extra 30 seconds of additional irradiation was administered and an additional attempt at crown's dislodgement was made. This latter process was repeated until the crown was retrieved **(Fig 1b)**. During the irradiation, temperatures of the crown, abutment, and implant fixture were also monitored similar to previous studies.[15,16,42]

Figure 1: Laser assisted implant crown removal experiments

(A) Cemented crown onto the implant abutment/implant fixture held using forceps during the irradiation process.

(B) After initial 240-second irradiation, an attempt was made to retrieve the crown. If no dislodgement was found, subsequent attempts were made every after 30-second irradiation.

After the first experiment for the Er:YAG group (G1 Er1), the crown specimens (n=10) were reused (G1 Er2) after their first successful crown removal to mimic the repeated clinical cementation. The leftover cement in these crowns' fitting surface was cleaned off via air-abrasion using 50 µm aluminum oxide particles and at a pressure of 2 pound per square inch (psi). The crowns were then recemented onto the zirconia abutments following the same initial cementing protocol and kept for 24 hours in 100% humidifying chamber prior to their consecutive crown removal attempt.

The total crown removal time for each crown in both groups was recorded and calculated by adding each extra 30 seconds needed to retrieve the crown to the initial 240 seconds of irradiation. The crown removal times were then analyzed for statistical significance using one-way analysis of variance (ANOVA: single factor, $\alpha = 0.05$).

To test for structural integrity and possible surface damage to the crown and abutment due to irradiation, the specimens were analyzed by SEM and EDS technologies. After the crown removal experiment, the underlying intaglio surface as well as the cameo surface of the crown and the cameo surface of the abutment were inspected using scanning electron microscopy (SEM) analysis (JEOL 6610LV, JEOL, Japan). Energy-dispersive X-ray spectroscopy (EDS) analysis was also used to examine the variations in the elemental composition of the crown, abutment as well as remaining cement if any. An extra zirconia crown and an extra zirconia abutment that had not gone through cementation and irradiation processes were used as control specimens. The specimens were not coated, and EDS was performed using a low vacuum mode in SEM with 20 kV energy range.

RESULTS

The average times needed to remove a zirconia crown from a zirconia implant abutment were 5 min 20 sec for G1 Er1 (first cementation and Er:YAG retrieval), 5 min 15 sec in G1 Er2 (second cementation and Er:YAG retrieval), and 5 min 55 sec in G2 (cementation and Er,Cr:YSGG retrieval). Overall, across all groups and subgroups there were no statistical differences observed in the removal times according to the ANOVA statistical analysis (p=0.32) **(Table 1)**. When irradiation applied to the cervical part of the crown from 1 to 10 minutes, the temperature ranges of the crown, abutment and implant fixtures were 21.3℃ to 27.7℃, 19.9℃ to 26.4℃, and 22.1℃ to 27.4℃, respectively. Note that the temperatures of the water ranged from 18.6℃ to 21.4℃.

Table 1: ANOVA statistical analysis for debond times (Seconds) of both pulsed erbium lasers

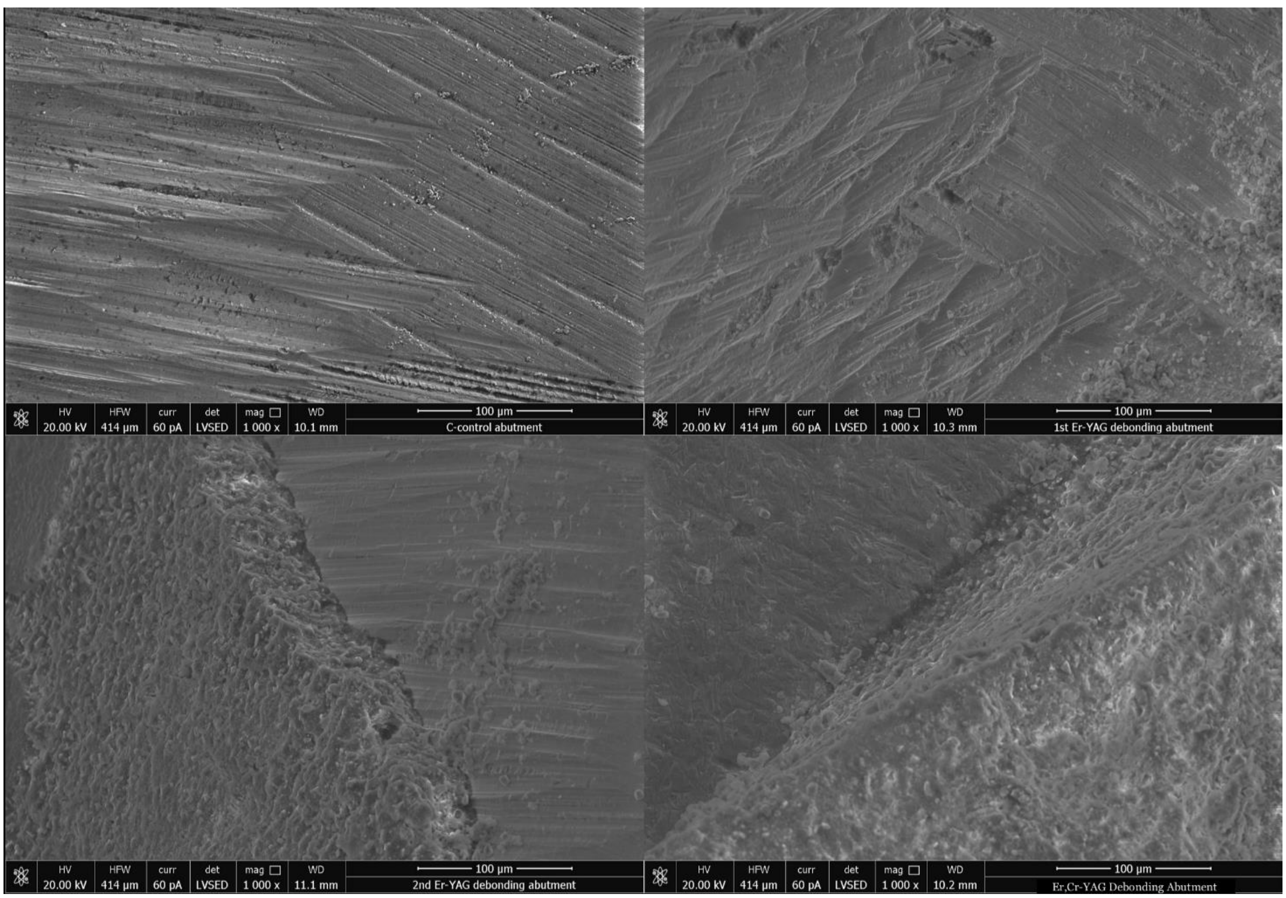
Grouping[$]	G1 [Er1]	G1 [Er2]	G2
Mean	312	309	333
SD	42.90	42.54	26.27
ANOVA*	P<0.05		
P Value	0.32		

[$]G1 [Er1]: Er:YAG cementation & 1st irradiation, G1 [Er2]: Er:YAG recementation & 2nd irradiation, G2: Er,Cr:YSGG cementation & irradiation
*Level of statistical significance, p<0.05

Abutment examination using SEM showed no major structural changes or damage suggestive of photoablation or thermal ablation **(Fig 2)**. The remaining cement appeared to stay on the abutment surface more than the crown surface. Additionally, no carbonization on the zirconia implant abutment or crown was observed. SEM analysis conducted to test the damage of the implant crown and abutment surface showed that all laser-assisted crown removal samples demonstrated no major noticeable cracks or fractures with macro and microstructure. Slight partial ablation of the cement during irradiation was occasionally observed. All the abutment groups demonstrated similar surface roughness and characters. The control abutment, that had no laser exposure or cementation, showed a clearly smoother surface than other samples with no cement remaining. The G1 Er1 group showed little cement remaining. The G1 Er2 and G2 groups showed more cement remaining than the G1 Er1 **(Fig 2)**.

Figure 2: SEM analyses of zirconia abutments

Control abutment with no laser exposure demonstrating the milled zirconia surface without any cement (Top Left), Er:YAG lasered zirconia abutment after first cementation (G1 Er1) with some remnant cement demonstrating similar zirconia surface (Top Right), Er:YAG lasered zirconia abutment after repeated cementation (G1 Er2) demonstrating zirconia surface and remnant cement (Bottom Left), and Er,Cr:YSGG lasered zirconia abutment (G2) with some remnant cement (Bottom Right). Note that more cement remained in the G1 Er2 and G2 groups.



For the crowns, the cameo surface of the control group appeared to be the smoothest. The cameo surfaces of the test samples, G1 Er1, G1 Er2 and G2, appeared to be slightly rougher suggesting the roughness increased from the irradiated glazed feldspathic surface. The intaglio surfaces of all groups appeared to be similar in the roughness. However, the first Er:YAG (G1 Er1) group showed less cement compared to the repeated Er:YAG (G1 Er2) and Er,Cr:YSGG (G2) groups **(Fig 3-6)**.

Figure 3: SEM analyses of control zirconia crown

(Top) Cameo surface of control zirconia crown demonstrated polished and glazed smooth zirconia surface with feldspathic porcelain glaze. (Bottom) Intaglio surface of control zirconia crown demonstrated milled and sintered zirconia surface.

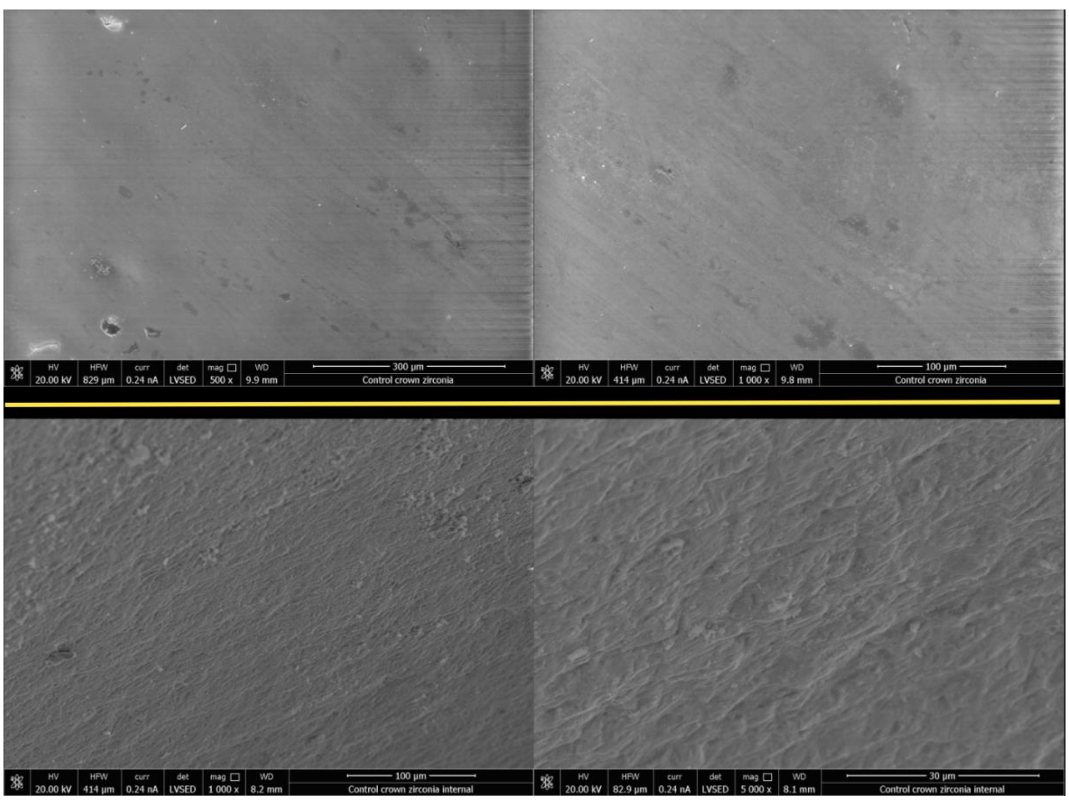


Figure 4: SEM analyses of Er:YAG lasered zirconia crown after first cementation (G1 Er1)

(Top) Cameo surface of the first time Er:YAG lasered zirconia crown demonstrated slightly rougher than the control. (Bottom) Intaglio surface of first time Er:YAG lasered zirconia crown demonstrated zirconia surfaces similar to the control little cement remaining.

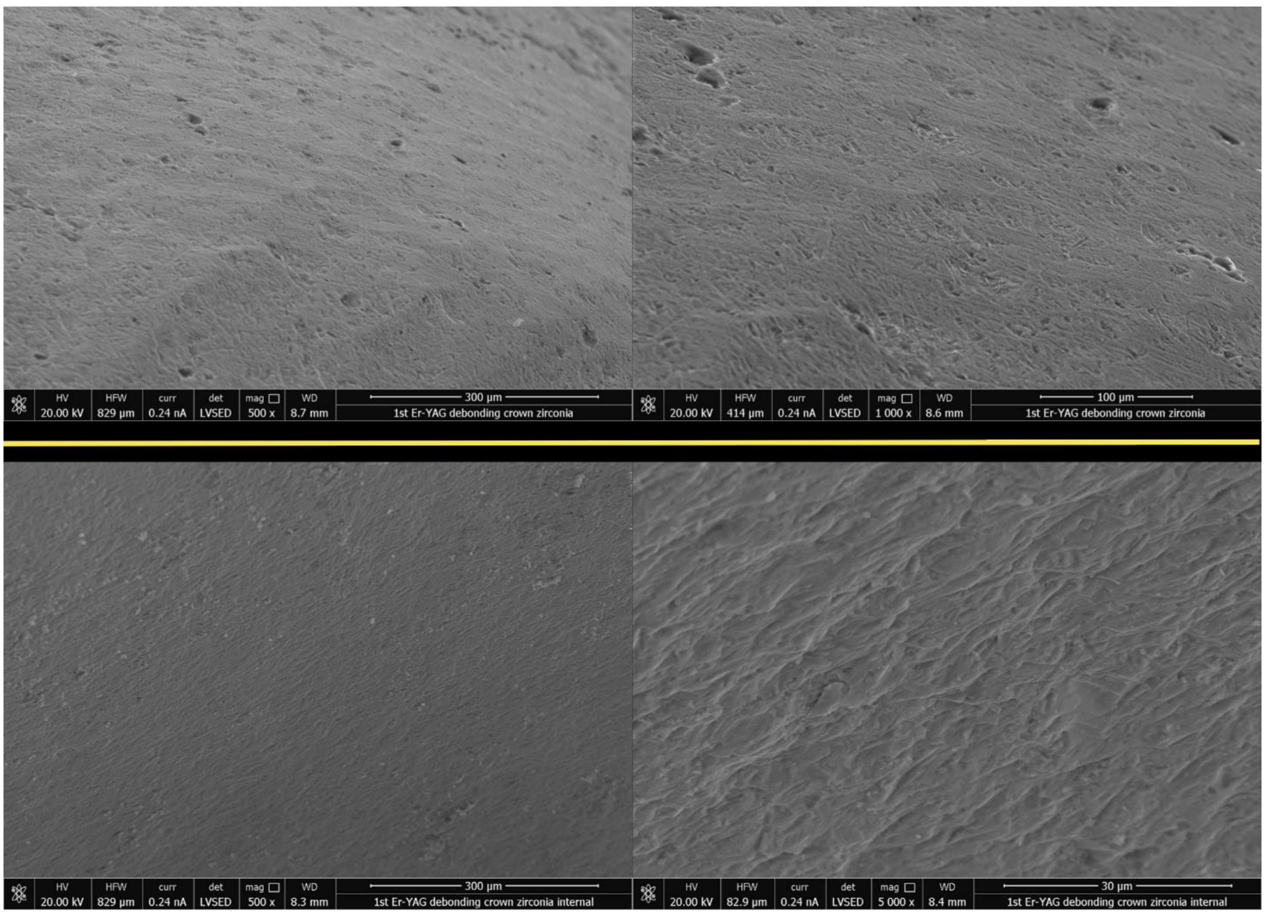


Figure 5: SEM analyses of Er:YAG lasered zirconia crown after repeated cementation (G1 Er2)

(Top) Cameo surface of the second time Er:YAG lasered zirconia crown demonstrated slightly rougher than the control similar to the first time Er:YAG lasered group. (Bottom) Intaglio surface of the second time Er:YAG lasered zirconia crown demonstrated zirconia surfaces similar to control and first time Er:YAG groups with more cement remaining.

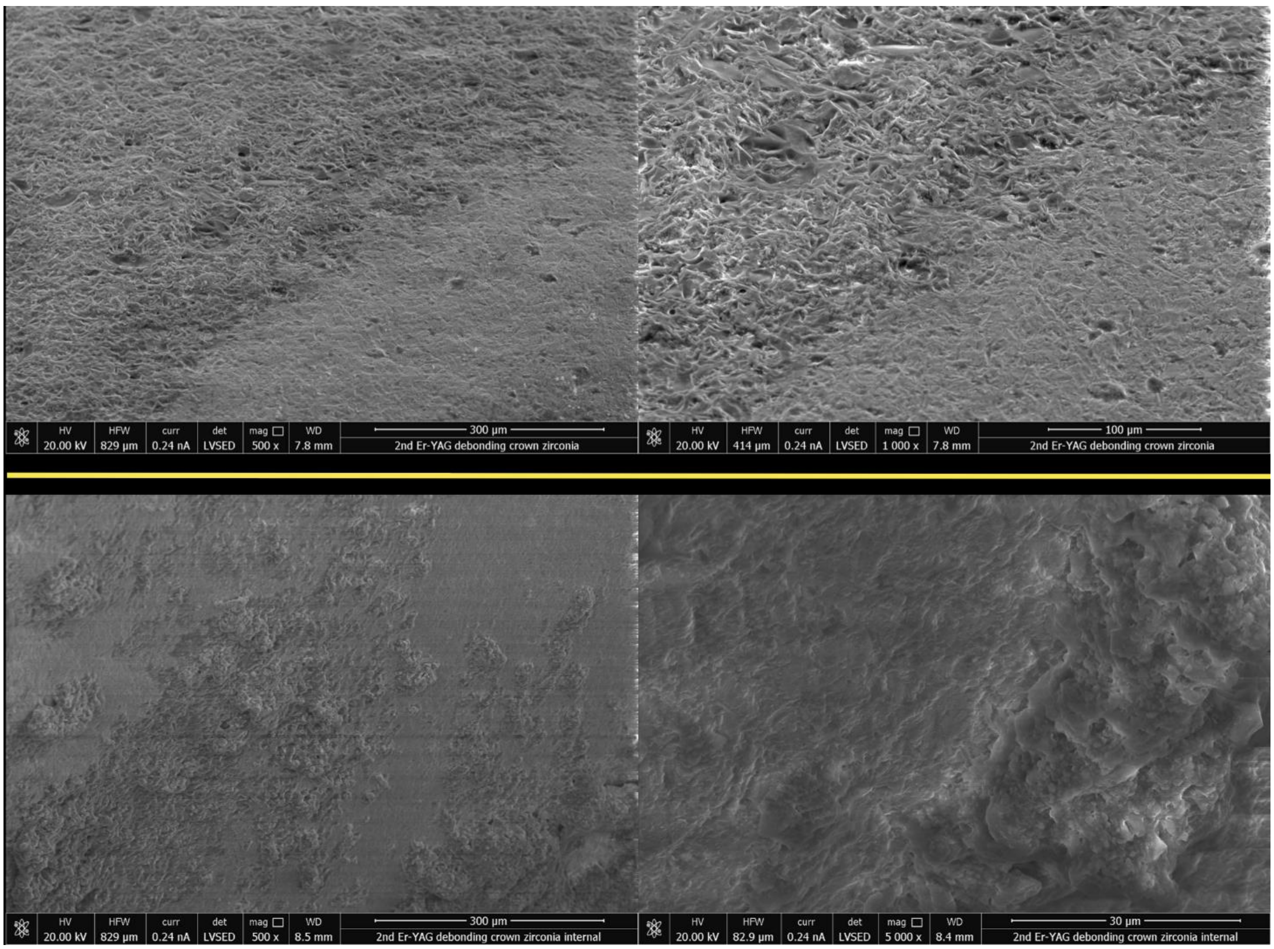
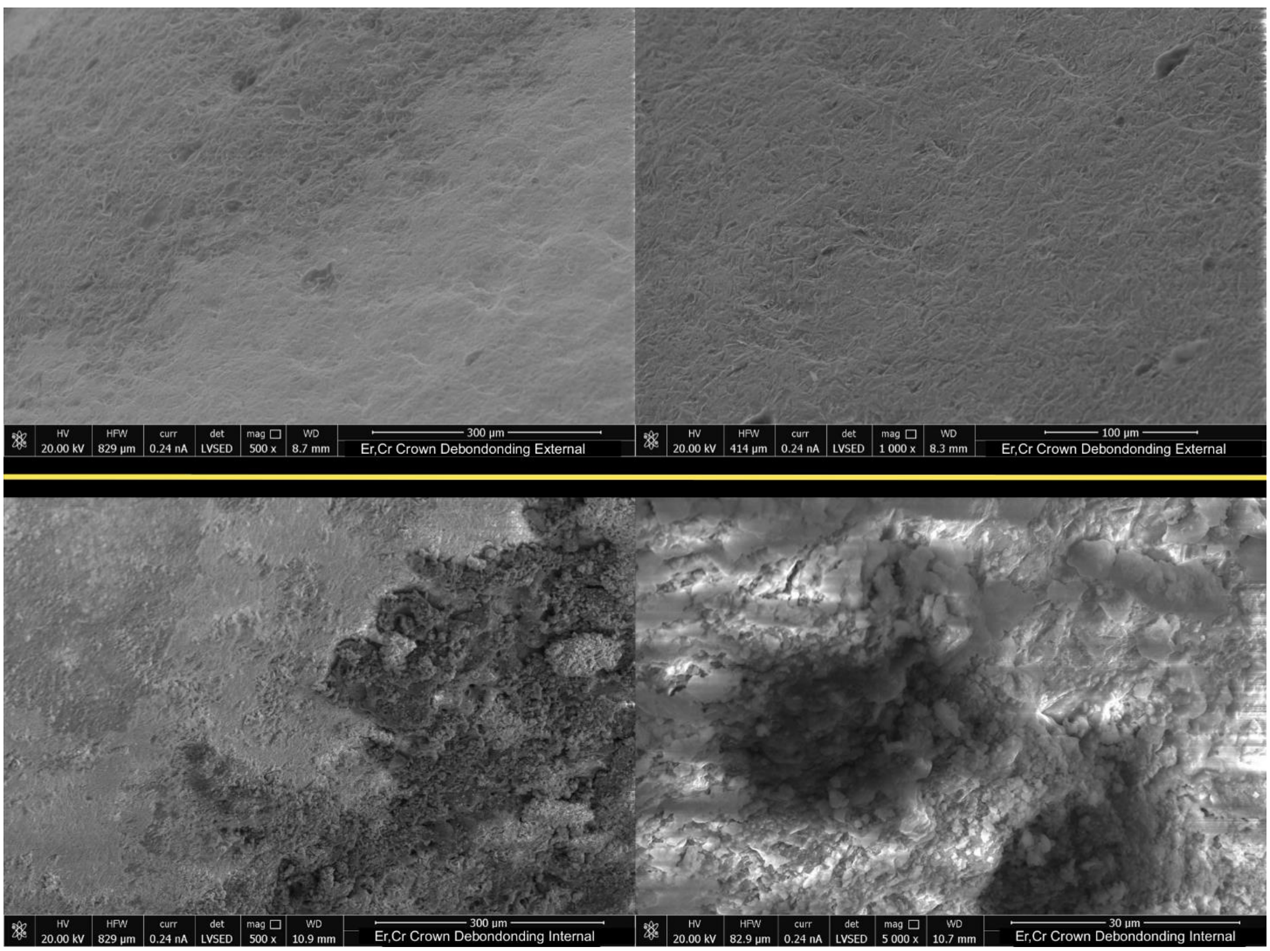


Figure 6: SEM analyses of Er,Cr:YSGG lasered zirconia crown after cementation (G2)

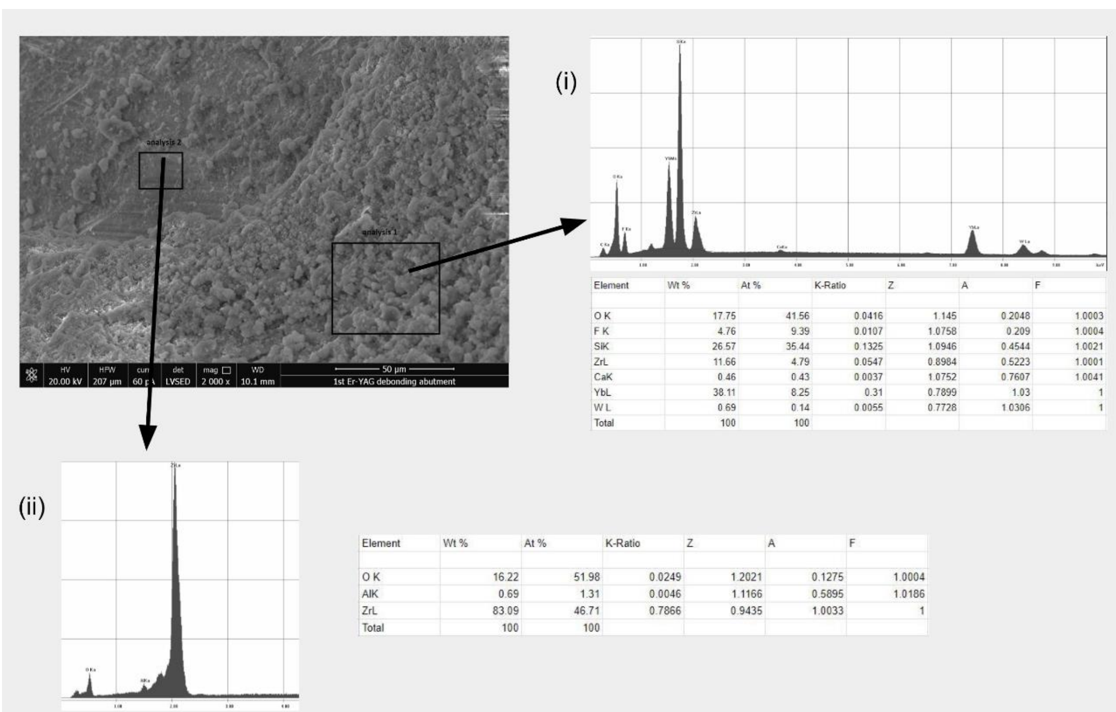
(Top) Cameo surface of Er,Cr:YSGG lasered zirconia crown demonstrated slightly rougher than control similar to first and repeated Er:YAG lasered groups. (Bottom) Intaglio surface of Er,Cr:YSGG lasered zirconia crown demonstrated zirconia surfaces similar to control and to first and repeated Er:YAG groups with more cement remaining than other groups.



In the EDS mode, the intaglio surfaces of the crown and the cameo surface of the abutment with and without remaining cement, were analyzed **(Fig 7)**. The EDS analyses were performed in three areas, the abutments with more and less cement remaining **(Fig 8),** and the crown **(Fig 9).** The EDS spectra and elemental compositions were very similar among the three groups in the less cement abutments and the crowns. However, the EDS analysis of the abutment with more cement remaining areas demonstrated a different spectra and elemental compositions for Er,Cr:YSGG compared to the Er:YAG groups perhaps from more cement remaining **(Fig 8)**.

Figure 7: Workflow for SEM/EDS analysis of zirconia abutment

The SEM figure (Top Left) demonstrates the area with less cement and more cement on the zirconia abutment surface. EDS analyses were performed for the area with less cement (i) and more cement (ii).

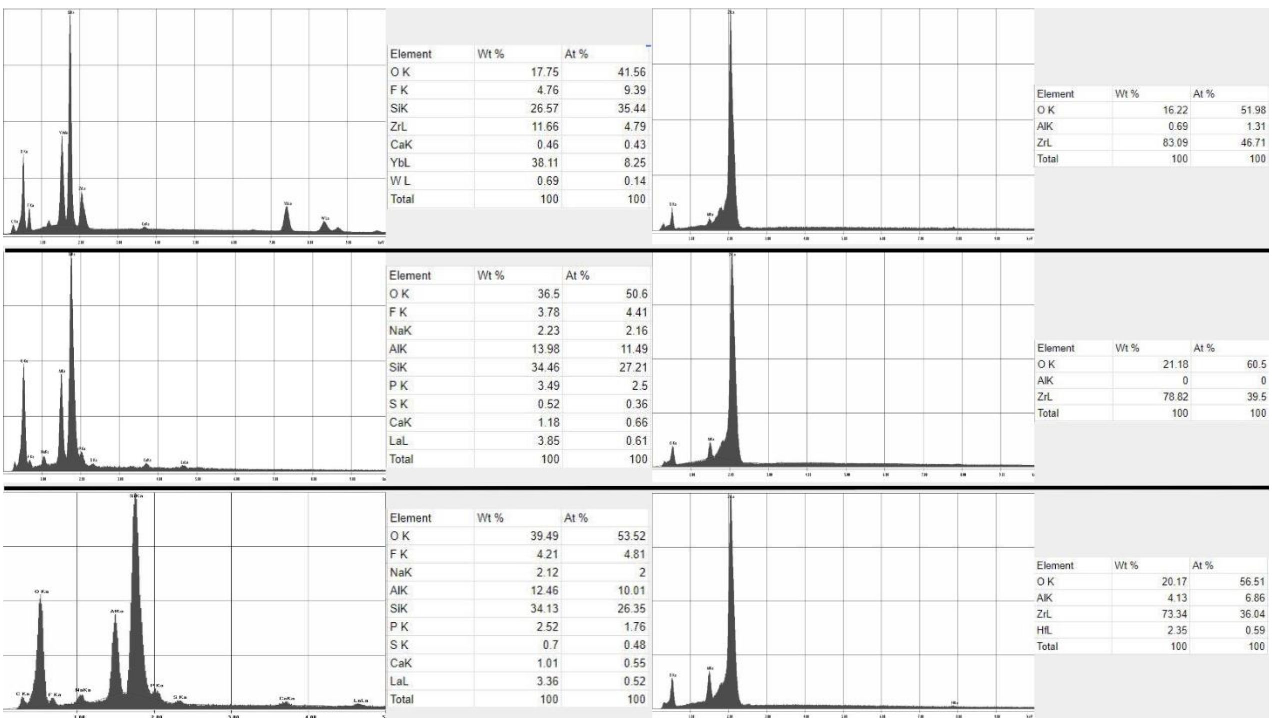


Element	Wt %	At %	K-Ratio	Z	A	F
O K	17.75	41.56	0.0416	1.145	0.2048	1.0003
F K	4.76	9.39	0.0107	1.0758	0.209	1.0004
SiK	26.57	35.44	0.1325	1.0946	0.4544	1.0021
ZrL	11.66	4.79	0.0547	0.8984	0.5223	1.0001
CaK	0.46	0.43	0.0037	1.0752	0.7607	1.0041
YbL	38.11	8.25	0.31	0.7899	1.03	1
W L	0.69	0.14	0.0055	0.7728	1.0306	1
Total	100	100				

Element	Wt %	At %	K-Ratio	Z	A	F
O K	16.22	51.98	0.0249	1.2021	0.1275	1.0004
AlK	0.69	1.31	0.0046	1.1166	0.5895	1.0186
ZrL	83.09	46.71	0.7866	0.9435	1.0033	1
Total	100	100				

Figure 8: EDS analyses of zirconia abutments

Spectra and elemental composition of abutment with first cement Er:YAG laser (G1 Er1) for more cement (Top Left) and less cement area (Top Right); spectra and elemental composition of abutment with repeated cement Er:YAG laser (G1 Er2) for more cement (Middle Left) and less cement area (Middle Right); and spectra and elemental composition of abutment with cement Er,Cr:YSGG laser (G2) for more cement (Bottom Left) and less cement area (Bottom Right). While all less cement abutment compositions were similar, there seemed to be more cement in G2 group as per different spectra/elemental compositions compared to other groups.



Element	Wt %	At %
O K	17.75	41.56
F K	4.76	9.39
SiK	26.57	35.44
ZrL	11.66	4.79
CaK	0.46	0.43
YbL	38.11	8.25
W L	0.69	0.14
Total	100	100

Element	Wt %	At %
O K	16.22	51.98
AlK	0.69	1.31
ZrL	83.09	46.71
Total	100	100

Element	Wt %	At %
O K	36.5	50.6
F K	3.78	4.41
NaK	2.23	2.16
AlK	13.98	11.49
SiK	34.46	27.21
P K	3.49	2.5
S K	0.52	0.36
CaK	1.18	0.66
LaL	3.85	0.61
Total	100	100

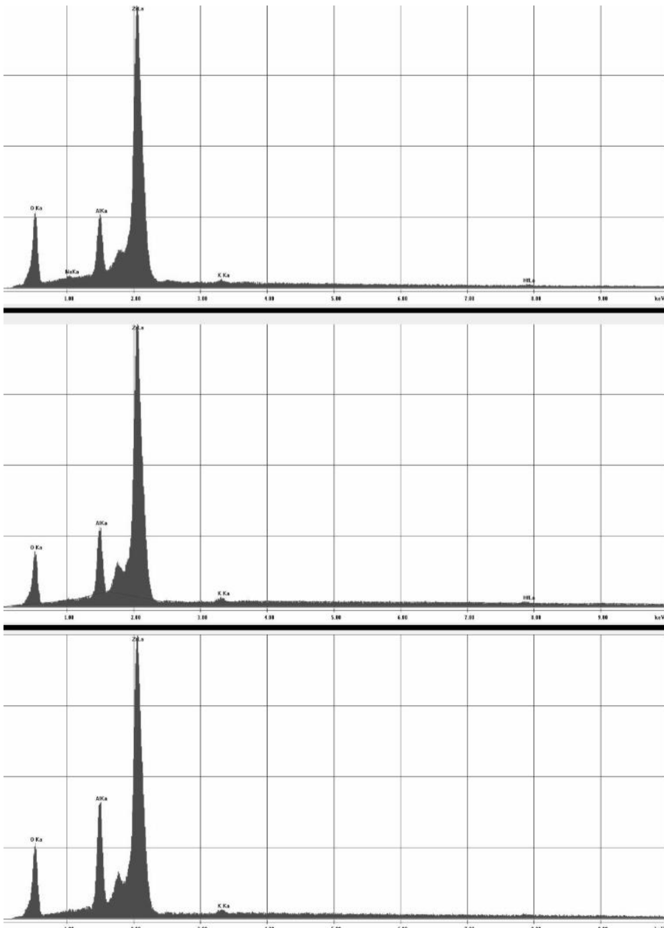
Element	Wt %	At %
O K	21.18	60.5
AlK	0	0
ZrL	78.82	39.5
Total	100	100

Element	Wt %	At %
O K	39.49	53.52
F K	4.21	4.81
NaK	2.12	2
AlK	12.46	10.01
SiK	34.13	26.35
P K	2.52	1.76
S K	0.7	0.48
CaK	1.01	0.55
LaL	3.36	0.52
Total	100	100

Element	Wt %	At %
O K	20.17	56.51
AlK	4.13	6.86
ZrL	73.34	36.04
HfL	2.35	0.59
Total	100	100

Figure 9: EDS analyses of zirconia crowns intaglio surface

Spectra and elemental composition of crown intaglio surface with first cement Er:YAG (G1 Er1) (Top), repeated cement Er:YAG (G1 Er2) (Middle), and Er,Cr:YSGG (G2) (Bottom) groups. All demonstrated similar spectra and elemental compositions.



Element	Wt %	At %
O K	29.14	66.05
NaK	0.37	0.58
AlK	5.73	7.7
ZrL	62.74	24.94
K K	0.42	0.39
HfL	1.6	0.32
Total	100	100

Element	Wt %	At %
O K	23.18	58.94
AlK	6.71	10.11
ZrL	65.77	29.34
K K	0.76	0.79
HfL	3.59	0.82
Total	100	100

Element	Wt %	At %
O K	28.05	62.5
AlK	9.72	12.84
ZrL	61.6	24.07
K K	0.64	0.58
Total	100	100

DISCUSSION

The use of erbium lasers in dental treatments can be utilized as a substitute for many conventional rotary instruments whilst proving to be more effective and less traumatic. In the case of removing cement-retained prosthesis, conventional methods can be very time consuming.[44] This can be further challenging when dealing with restorations made of zirconia, which are considered to be one of the strongest materials available for restorative treatments.[6,44] Beyond time being a factor, conventional methods are often damaging to the retrieved prosthesis, rendering them unusable, which requires fabricating new crowns/restorations, adding extra costs and time for patients and practitioners.[15,16] Hence, the findings of this research suggests that erbium pulsed lasers can not only facilitate the removal of zirconia crowns from zirconia implant abutments within a short period of time (~ 5 to 6 minutes on average), but also offer a more conservative and less invasive treatment approach. Therefore, erbium pulsed lasers should be considered as a valuable option especially when retrieval of cement-retained implant restorations are indicated. Moreover, previous studies have been done on different types of crown material, however, this study comes with greater significance as it is more clinically relevant. This is due to the fact that zirconia crowns are much more commonly used for implant treatments as they are stronger, cheaper, and opaque, obscuring the abutment that can show through the crown.

The results suggest that both erbium pulsed lasers, Er:YAG and Er,Cr:YSGG, can be used successfully to retrieve zirconia crowns from zirconia implant abutments. Laser-assisted crown removal times were recorded to be around 5 minutes for both lasers with the temperature ranges of ~21°C to 28°C was about 2°C higher than previous report of removing a lithium disilicate crown from a titanium or zirconia implant abutment.[15,16] The slightly higher temperatures may due to the different crown materials, however the temperature increase remains to impose no threat for tissue damage. There were no statistical differences when comparing the crown removal times of the two lasers, nor when comparing the crown removal times for the same laser, Er:YAG, after repeated cementation. This suggests that the two erbium pulsed lasers may have similar mechanisms and may be used interchangeably to retrieve a zirconia implant crown. The two lasers having similar crown removal times despite having different wavelengths can be attributed to the fact that both lasers' wavelength fall in the mid-infrared spectrum where water remains the target chromophore. Therefore, the laser's functionality does not change.

Er:YAG and Er,Cr:YSGG lasers while both are erbium pulsed lasers, they have different pulse mechanisms in energizing the flashlamp, source of the laser energy. Er,Cr:YSGG uses the older technology known as Pulse Forming Network (PFN), while Er:YAG uses the newer technology known as Variable Square Pulse (VSP).[22] PFN pulses have a bell shape with usually fixed duration. VSP pulses have a square shape with variable pulse duration. While the energy pulses may seem to be similar because of the different pulsed energy generated, it may behave differently in the oral hard tissues or different dental materials.[21] In general, it appears that Er,Cr:YSGG laser is less effective but penetrates deeper and not as localized as Er:YAG in the dentin.[21,45–47] Perhaps such differences are highlighted when noting that the Er,Cr:YSGG laser debond times are a lot more consistent and don't have a lot of variation compared to Er:YAG debond times. Such observation is perhaps attributed to the fact that Er,Cr:YSGG laser has better penetrating power, hence irradiation to all crown surfaces are done more consistently. However, the Er:YAG laser irradiation with its weaker penetration power can sustain some variation in its debonding potential depending on the surface area of the crown. Despite the superior penetration of the Er,Cr:YSGG and its consistent debond times, it still remains slightly less effective than the Er:YAG laser. While not statistically significant, Er,Cr:YSGG debond times averaged 30 seconds more than the Er:YAG.

Similar parameters were used for both lasers to closely match the final laser output. It is also important to note that the type of material used in crown fabrication could have a significant impact on the crown removing times, even when using the same type of laser and parameters. A previous study that utilizes the same Er:YAG laser showed that the time required to remove lithium disilicate crowns from zirconia abutments was considerably shorter, relative to the zirconia crowns used in this study.[15,16] The previous studies [15,16] where the same laser parameters and irradiation protocol, the required time to retrieve lithium disilicate crowns from zirconia abutments was approximately 3 minutes, compared to approximately 5 minutes for zirconia crowns in this study. Such differences can be attributed to the fact that zirconia crowns have a more crystalline structure compared to lithium disilicate, making zirconia a more difficult substrate for lasers to penetrate. This ~5 min removal time of a zirconia implant crown is also similar to a previous study using Er:YAG laser to remove a zirconia crown from a natural tooth abutment.[34] Therefore, it is suggested that dentists should factor in the type of material of a restoration used when estimating the time needed to dislodge fixed dental prosthesis if frequent removals of the particular prostheses is expected.

Interestingly, when compared to the previous study, this study showed consistent results for crown removal times after short-term repeated cementation.[16] New cementation and repeated cementation of zirconia crowns to zirconia abutments experienced minimal change for the required time for crown removal using Er:YAG laser. This remains consistent with the previous study that shows repeated cementation of lithium disilicate crowns on zirconia abutments also experienced no significant change in the crown removal times. This suggests that despite individual differences in type of material and overall crown removal times, dentists should expect little changes in how an implant crown would be removed when subjected to multiple short-term recementations.

Another core prerequisite for the success of this study was to prove that pulsed erbium lasers do not damage the retrieved prosthesis in the process, as the option to reuse retrieved restoration is a major advantage over conventional methods. SEM/EDS analyses for this study following Er:YAG and Er,Cr:YSGG irradiation showed no visual damage to any crown or abutment nor any macro- or micro- structural surface damage. These findings are consistent with previous Er:YAG studies for lithium disilicate crowns/zirconia- or titanium implant abutments.[15,16] SEM/EDS analyses have been used to examine zirconia/porcelain veneer interface[48] as well as zirconia bonding to self-adhesive resin cement.[49] EDS analyses provide additional insights into the elemental composition of irradiated zirconia abutments and crowns that seems to have no damaging effect from erbium laser irradiation. However, in this study, slightly increased surface roughness of the cameo surface of the crown was seen as a result of laser exposure. It is possible that that the laser may have roughen the feldspathic porcelain similar other studies.[50]

A study using Er,Cr:YSGG laser to remove lithium disilicate crowns from natural teeth, showed a lesser time of removal (~1-3 min)[35,51] This may have been a result of a different type or thickness of restorations, different type of cements, and a higher energy setting. Previous studies suggested that the Er,Cr:YSGG laser is less efficient compared to Er:YAG.[35,51,52] However, in this current study, the zirconia crown removal times were slightly longer for the Er,Cr:YSGG group compared to the Er:YAG without statistical significance. The Fourier Transform Infrared Spectroscopy (FTIR), method used to measure material energy absorption, demonstrates a broad H_2O/OH absorption band of wavelengths in the range of 3,750–3,640 and 3,600–3,400 nm.[51,52] Similarly, composite resin cements, such as Multilink (Ivoclar Vivadent) demonstrate a distinct absorption peak at ~3,401 nm. These ranges coincide with the erbium pulsed laser emission wavelength where there was little radiation absorption to zirconia material.[32–34] Thus, this allows debonding via irradiation energization of cement with little or no damage to the crown materials.

While this study showed minor physical or composition changes of the zirconia material with no statistical differences in the crown removal time, the effects from laser induced changes of the material surface at small micro- and nanoscale remain unclear. There was more cement remaining in the crown and abutment of the repeated cement Er:YAG and Er,Cr:YSGG groups in the current study. The SEM observation was also confirmed by the EDS analyses that Er,Cr:YSGG group demonstrated most cement remaining on the crown intaglio surface. Some evidence suggested that the zirconia treatments with Er:YAG and Er,Cr:YSGG improve surface roughness and likely increase the bond strength to the resin cement.[53–56] The improved roughness and bond strength to the resin as a result of laser treatment at the pre-sinter stage are significant and maybe an alternative to air abrasion. The laser effects after the sintering process appear to have only limited or no improvement of resin bonding strength.[53,57,58] The Er:YAG and Nd:YAG laser treatments can, at higher energy settings than this study, produce microcracks in the zirconia that may improve retention with the resin cement.[53]

It is interesting to note that in this study, the lasers were applied to the cervical area of the buccal and lingual surfaces of the crown. It is known that both Er:YAG and Er,Cr:YSGG lasers can create microroughness on the surface of feldspathic porcelain (which was used as glaze material for the crown in this current study) and further improve porcelain-resin bonding.[50,59] The visual increase in micro-roughness on the surface of the laser-irradiated areas was not observed in this study. The results are similar to Er:YAG laser treatment to the zirconia dental implants. Er:YAG seems to penetrate through the zirconia material without any effect on the surface or the material itself.[60]

There are some limitations to the study. First, limitations of an *in vitro* study are recognized. Since the crowns were irradiated separate from the cast, allowing for optimal access to all surfaces, it is likely that applications of these two lasers intraorally may not be as effective due to access limitations such as cheek, tongue, limited mouth opening. Second, it is not known how the laser may affect soft tissue attachment or microbial biofilm adherence. While the microroughness of the sintered monolithic zirconia is minimal, the nano-roughness of zirconia material as well as the roughness of the feldspathic porcelain glaze may alter soft tissue attachment or biofilm adherence. Majority of literature on removing biofilm with Er:YAG laser suggest that it is effective in removing biofilm with no change in the zirconia dental implant structures.[60–63] However, Er,Cr:YSGG laser may have some effects on the roughness of zirconia surface.[62] Further analyses of both lasers in the biological system or *in vivo* are therefore needed. Third, there is no repeated cementation for Er,Cr:YSGG laser group in this current study. Since the Er:YAG has been studied more thoroughly on the removal of implant crowns from implant abutments, in the current study Er,Cr:YSGG was being explored and compared. Future studies including the temperature changes with different types of crown/abutment materials and cements will be needed for Er,Cr:YSGG laser. Lastly, the Zirconia abutments and implants were prefabricated, not customizable. In real life clinical applications those implants, and abutments are customizable, meaning they come in different dimensions that best fit the patients, hence such variability can play a factor in laser debond efficiency which is worth exploring in future studies.

CONCLUSIONS

Repeated cementation of a zirconia crown onto a zirconia abutment following irradiation using Er:YAG laser, had no effect on the crown removal time. When comparing the crown removal times for the two pulsed erbium lasers, Er:YAG and Er,Cr:YSGG, no statistically significant difference was observed. Lastly, upon examination with SEM and EDS no surface structure damage was observed nor a change in material composition was experienced following Er:YAG irradiation. Both Er:YAG and Er,Cr:YSGG lasers are effective and non-invasive tools for retrieving a zirconia crown from a zirconia implant abutment.

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