

Article

Utilization of Er:YAG Laser in Retrieving and Reusing of Lithium Disilicate and Zirconia Monolithic Crowns in Natural Teeth: An *in Vitro* Study

Kinga Grzech-Leśniak^{a,b} Sompop Bencharit^{c,d,e,*} Lenart Skrjanc^f Domen Kanduti^g Jacek Matys^h and Janina Golob Deeb^a

^aDepartment of Periodontology, School of Dentistry, Virginia Commonwealth University, Richmond, Virginia, United States of America, and

^bDepartment of Oral Surgery, Wroclaw Medical University, Wroclaw, Poland

^cDepartment of General Practice, School of Dentistry, Virginia Commonwealth University, Richmond, Virginia, United States of America,

^dDepartment of Oral and Maxillofacial Surgery, School of Dentistry, Virginia Commonwealth University, Richmond, Virginia, United States of America,

^eDepartment of Biomedical Engineering, College of Engineering, Virginia Commonwealth University, Richmond, Virginia, United States of America,

^fFaculty of Medicine, University of Ljubljana

^gDepartment of Periodontology, Faculty of Medicine, University of Ljubljana

^hDepartment of Oral Surgery, Wroclaw Medical University, Wroclaw, Poland

*Corresponding: Author:Sompop Bencharit; Email: sbencharit@vcu.edu

Abstract: The study examined the effect of noninvasive crown retrieval/reuse process using erbium-doped yttrium aluminum garnet laser (Er:YAG). Twenty-six extracted human teeth were prepared for a crown. The crown was milled using lithium disilicate (LD) and zirconia (Z) materials, n=13 per group, 3 for scanning electron microscopy (SEM). The crown was luted using composite resin cement and subjected to a laser retrieval process. After the retrieval process, the crown was cleaned, recemented and laser-retrieved two more times, without and with additional tooth reduction mimicking clinical refreshment of dentin. Retrieval time and temperature were analyzed using analysis of variance (ANOVA). Surface changes were observed through SEM. The retrieval times were 267.1±130.43, 220±79.09, 277.1±126.44, 368.4±136.14, 355±159.39, and 419.2±121.36 seconds for first, second, third LD and Z groups, respectively (p=.009). The maximal temperatures were 23.95.1±1.89°C, 24.86±2.01°C, 24.17±1.53°C, 22.88±1.51°C, 24.03±1.74°C, and 21.99±1.32°C for first, second, third LD and Z groups, respectively (p=.006). Er:YAG laser crown removal is an effective retrieval tool for all-ceramic crowns. Minimal changes to teeth and crowns were observed following laser irradiation.

Keywords: Crown removal; Debond; Er:YAG; Laser; Lithium disilicate; Zirconia

Featured Application: This work demonstrates that Er:YAG laser can be used as a non-invasive crown retrieval tool for common all-ceramic crowns. The type of all-ceramic material has a significant impact on crown removal time. However, the cement thickness has less influence on retrieval time or temperature. The temperature increase during laser irradiation does not appear to be harmful or clinically significant.

1. Introduction

Recent advancement of digital technologies including intraoral scanning, computer-aided design and computer-aided manufacturing (CAD/CAM), as well as biomaterials allow dentists to fabricate fixed prostheses such as a crown in a rapid streamline process.[1–4] These crowns, most frequently made of ceramic materials such as lithium disilicate or zirconia, are esthetically pleasing, with superior biocompatibility and physical properties as well as survival rates.[5–7] The crown material, especially lithium disilicate, can be bonded to the natural tooth abutment using acid etching and composite resin cement,[8–10] while zirconia materials used to make these crowns belong to perhaps the strongest ceramic materials used in dentistry.[11,12] These physical strengths and bonding capabilities allow for long lasting restorations in the oral cavity. These clinically desirable properties however become a major obstacle when the crown needs to be removed.[13,14] When the crown retrieval is indicated due to recurrent caries, misfit, esthetic reasons, material damage or need for endodontic therapy, a rotary handpiece with a cutting bur is a conventional method to remove the crown. This process leads to the irreversible damage of the crown and possibly the tooth resulting in a need for a new restoration rendering the process time consuming and costly for dentist and patient. Ideally, the dentist would be able to retrieve the crown from the abutment tooth atraumatically and quickly without damaging the crown or tooth and be able to re-cemented the crown back onto the tooth. Such a process would reduce chairtime, discomfort, time, frustration, and cost to both the provider and the patient.

The use of lasers for removal of restorative materials from natural teeth or dental implants is not new. High power lasers such as erbium-doped yttrium aluminum garnet laser (Er:YAG) have been used to retrieve all-ceramic restorations.[15,16] The energy wavelength of 2940 nm is passed through the translucent ceramic material with little absorption and targets the water and monomer molecules in the cement layer. The energized water and monomer molecules create an ablation cascade of cement and therefore the all-ceramic restorations can be retrieved without any structural damage to the crown or to the natural abutment tooth. Er:YAG laser has been used to remove composite resin restorations,[17] veneers,[18,19] orthodontic brackets[20,21] and crowns.[22] Recent studies used Er:YAG laser to retrieve lithium disilicate crowns from zirconia or titanium implant abutments[23–25] and zirconia crowns from zirconia implant abutments[25] in a few minutes without any damage to the crown or abutment materials. These studies also demonstrate the ability of the Er:YAG laser to retrieve and reuse all-ceramic (lithium disilicate or zirconia) crowns multiple times without any damages to the dental implant crown or abutment materials.[23–25] While there is clinical and research evidence for removing all-ceramic crowns with Er:YAG laser, there is little information available on the repeated laser-assisted crown retrievals and reuses for natural abutment teeth and of the effect different restorative materials may have on the length of laser irradiation needed for this process.

The study was aimed to examine the effects of Er:YAG laser in the repeated crown retrieval process from natural teeth using the most common all-ceramic materials for crowns, lithium disilicate and zirconia. The hypothesis was that with an Er:YAG laser, retrieval of a lithium disilicate crown would take less time and result in higher intra-pulpal temperature compared to a zirconia crown. Additional goal was to examine any structural surface damage to the materials or teeth as a result of repeated irradiation during the crown retrieval process.

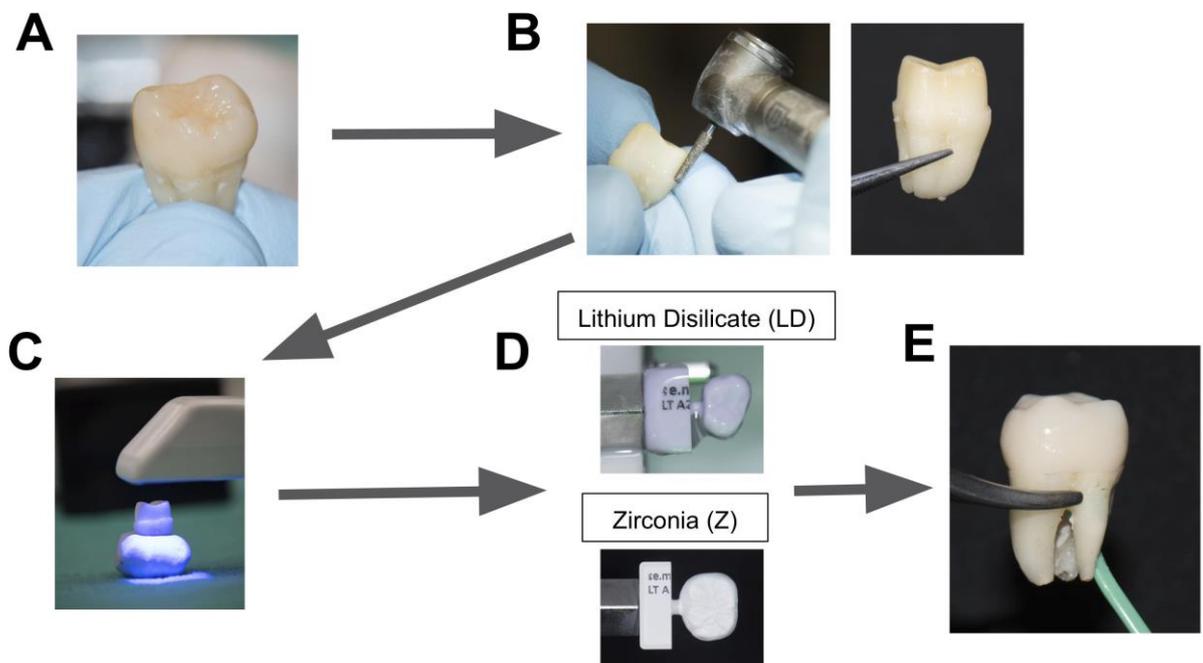
2. Materials and Methods

2.1. Specimen preparation

Specimen preparation process is shown in **Figure 1**. Twenty-six recently extracted human molars were used. Teeth were kept in distilled water during the waiting period for specimen preparation. Each tooth specimen was prepared past dentino-enamel junction into dentin to accommodate a lithium disilicate or zirconia crown with material thickness of 1 millimeter (mm) axially and 1.5 mm occlusally using a dental rotary handpiece and diamond burs with generous air and water coolant. A 0.5 mm deep chamfer finishing line was used. After the tooth preparation, the specimen was

scanned using an intraoral scanner (Emerald, Planmeca, Helsinki, Finland). The crown was virtually designed using CAD software (Romexis version 5.1, Planmeca, Helsinki, Finland). The material thickness of ~0.5 mm at the crown margin and ~1-1.5 mm axially and occlusally was used. The cement gap was designed as 100 μm .

Figure 1. Specimen preparation. A) Recently discarded extracted natural teeth were selected and cleaned, B) the tooth was prepared for the crown, C) the tooth was scanned using an intraoral scanner and the digital design was done, D) the crown was milled, E) the crown was cemented and the temperature probe was inserted.



For the lithium disilicate crown, the crown design was exported into a standard tessellation language (STL) format to be milled. A pre-sintered monolithic lithium disilicate block (IPS e.max CAD C14 LT A2, Ivoclar Vivadent, Schaan, Liechtenstein) was milled using a single spindle desktop milling machine (PlanMill 30S, Planmeca, Helsinki, Finland). The pre-sintered milled crown was then stained, characterized with feldspathic porcelain, and sintered using the manufacturer's recommended combined staining, glazing and crystallization protocol in a ceramic furnace (Programat CS3, Ivoclar Vivadent, Schaan, Liechtenstein) for ~15 min in the furnace or ~45 min total time including the preheating and subsequent cooling of the furnace. The excess glaze around the margin was removed and the crown was polished. The luting protocol was based on the manufacturer's recommendation. The crown was tried to determine appropriate fitting and then luted with composite resin cement (Multilink Automix, Ivoclar Vivadent, Schaan, Liechtenstein). Briefly, the crown was steam-cleaned, etched with 5% hydrofluoric acid (IPS Ceramic Etching Gel, Ivoclar Vivadent, Schaan, Liechtenstein) for 20 seconds (sec), rinsed with water and air dried, conditioned with silane for 60 sec (Monobond Plus, Ivoclar Vivadent, Schaan, Liechtenstein) and then air dried. The abutment was primed for 30 sec with a mixture primers per manufacturer's recommendation (Primer A and B, Multilink, Ivoclar Vivadent, Schaan, Liechtenstein). The crown was pressed with finger-pressure for about 5 min. Light polymerization for 20 sec for each axial and occlusal surface was performed. The cemented specimen was kept in a 100% humidity chamber using distilled water for at least 48 hours before crown retrieval.

For the zirconia crown, the crown design was exported and milled using a single spindle desktop milling machine (PlanMill 30S, Planmeca, Helsinki, Finland) out of a monolithic 3 mol% yttria stabilized tetragonal zirconia polycrystal (3Y-TZP) block (IPS e.max ZirCAD LT C17 A2, Ivoclar Vivadent, Schaan, Liechtenstein). The milled crown was sintered for 45 minutes per manufacturer's recommendation using a sintering furnace (Programat CS4, Ivoclar Vivadent, Schaan, Liechtenstein).

After sintering, the crown was characterized and stained using the same furnace (Programat CS4, Ivoclar Vivadent, Schaan, Liechtenstein). The intaglio surface of the glazed crowns was then again air-abraded with 50 µm aluminum oxide particles. Excess glaze around the margin was removed. The crown was polished and tried on the abutment to determine the fitting. The crown was conditioned with silane for 60 sec (Monobond Plus, Ivoclar Vivadent, Schaan, Liechtenstein) and then air dried. The cement and cementation process with composite resin cement (Multilink Automix, Ivoclar Vivadent, Schaan, Liechtenstein) was the same as the one for lithium disilicate crowns. The cemented specimen was kept in a 100% humidity chamber using distilled water for at least 48 hours before crown retrieval.

2.2. Specimen assignment, treatment, and retrieval process

The study workflow and grouping are shown in **Figure 1**. A total of 13 cemented crown specimens for each group were made. Grouping was assigned per material LD for lithium disilicate and Z for zirconia. Initially all 26 specimens underwent the laser-assisted crown retrieval process. One specimen from each group was removed for scanning electron microscopy (SEM) examination. These first retrieval attempts were recorded as LD1 and Z1.

After the first crown retrieval, the crowns and the abutment teeth were air abraded and rinsed with water. The crowns were then re-cemented using the same luting processes as described above. The second retrieval was performed under the same laser parameters and recorded as LD2 and Z2 attempt. The second retrieval attempt mimicked the clinical recementation process when no major alteration and adjustment of the natural tooth abutment is needed. One specimen from each group was again removed for SEM examination. Following the second crown retrieval, the crowns were again air abraded and rinsed with water. The abutment teeth were additionally reduced using a handpiece and diamond burs to simulate adjustments sometimes indicated following crown retrieval in clinical practice. Attempts were made to uniformly adjust the axial and occlusal surfaces of the teeth without disturbing the integrity of the margins.

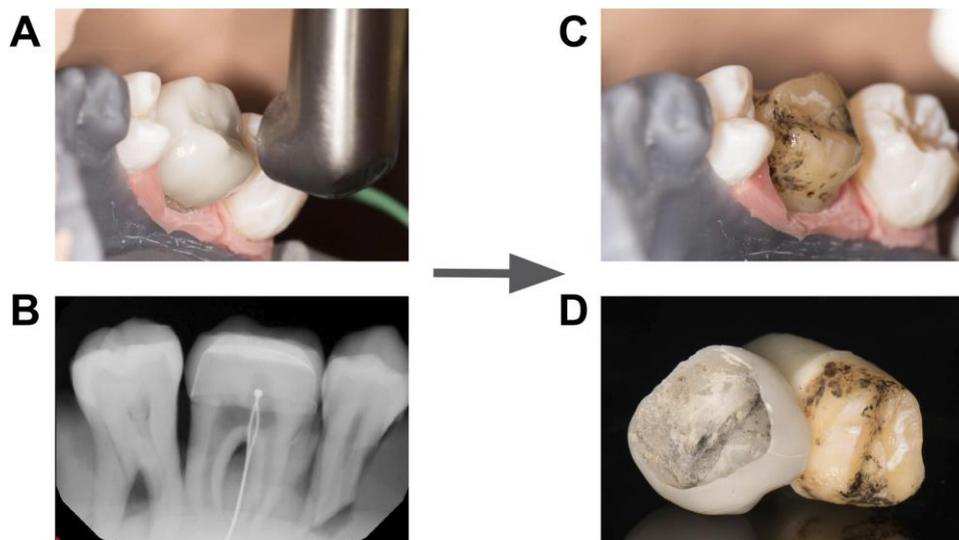
Following the additional tooth reduction, teeth were scanned again using the same intraoral scanner to capture the surface area changes. The abutment surfaces and the new cement spaces were calculated using MeshMixer software (version 3.5, Autodesk, USA).

The crowns were then re-cemented using the same cementation protocol per type of crown material, kept in a 100% humidity chamber using distilled water for 48 hours and retrieved. These retrieval attempts were recorded as LD3 and Z3. One specimen from each group was kept for SEM analysis.

2.3. Laser assisted crown retrieval process

An apical channel was prepared through the furcation of the tooth into the pulpal chamber to insert the thermometer probe for a microthermal couple element (Adv. Thermocouple Therm. w/ RS232 Output Datalogger Type K- 800008, Super Scientific Works Pvt. Ltd.) to measure the temperature changes during the laser-assisted crown retrieval process (**Fig 1 and 2**). The cemented crown/abutment specimen was mounted into a 3-D printed typodont with adjacent natural teeth to simulate a clinical situation during laser irradiation. (**Fig 2**).

Figure 2. Laser-assisted crown removal. A) Laser irradiation, B) Radiograph showing temperature probe positioning, C) Abutment after crown removal, and D) crown and abutment specimens after crown removal.



Similar to previous studies,[23,24] Er:YAG laser (Lightwalker, Fotona, Slovenia) was set at: 300 mJ, 15 Hz, 4.5 W, spot size 0.9 mm, fluence per pulse 47.16 J/cm², power density 707.4 W/cm², operation mode: quantum square pulse (QSP) mode (50 μs pulse duration) 2 water/2 air. Using a non-contact continuous motion tipless handpiece (HO2, Lightwalker, Fotona, Slovenia), the crown was irradiated buccally, lingually, occlusally and indirectly interproximally at a distance of 6-10 mm. Following 2 min of irradiation time, the crown was gently tapped with a traditional crown removal instrument on the buccal and lingual margins, simulating clinical access to those surfaces. If removal could not be achieved, the tooth was subjected to additional 30 second intervals of irradiation followed by the attempt of crown removal after each of the intervals. The irradiation time was recorded until the crown was successfully retrieved either by tapping, light digital manipulation or passively lifting off during the irradiation. (**Fig 2**). Before initiating the crown removal, pulpal temperatures were recorded at the baseline and throughout the entire procedure at 30 sec intervals until the crown was retrieved.

After the first, second, and third crown retrieval experiment, one specimen for each group was withheld for SEM analysis. To examine the surface integrity of the crown after each irradiation and crown retrieval, the underlying intaglio surface of the crown was examined using scanning electron microscopy (SEM) analysis (JEOL 6610LV, JEOL, Japan). Similar to the previous studies,[23,24] secondary electron imaging (SEI) to topography of the structure analysis was applied to enhance structural assessment and visualization of possible cracks using back-scattered electrons (BSE).

2.4. Measurements and Statistical Analyses

The lithium disilicate crown retrieval measurements included the first retrieval (LD1), the second retrieval (LD2: recemented without abutment adjustment), and the third retrieval (LD3: recemented with abutment adjustment). Similarly, the zirconia crown retrieval measurements included the first retrieval (Z1), the second retrieval (Z2: recemented without abutment adjustment), and the third retrieval (Z3: recemented with abutment adjustment). Data analysis was performed only on the specimens that had gone through all three retrievals (n=10 for each group). The crown retrieval time and the highest temperature from each group were statistically analyzed using analysis of variance (ANOVA, single factor) with level of significance, $\alpha=0.05$. The null hypotheses were that there was no statistical difference among the group of different materials, lithium disilicate and zirconia, and with different retrieval attempts (1, 2, and 3). ANOVA with $\alpha=0.05$ was used to examine the statistical difference within the same material. T-test assuming unequal variances with $\alpha=0.05$ was

used to determine the difference between materials for each retrieval. To examine the effects of tooth alteration in the third retrieval, Pearson correlations were calculated for the abutment surface and retrieval time for the first and third retrieval, as well as the cement layer and retrieval time/temperature.

3. Results

The summary of the results are shown in **Table 1 and 2**. The average crown retrieval times for lithium disilicate were 267.1±130.43, 220±79.09, 277.1±126.44 sec for LD1, LD2 and LD3, respectively. On the other hand, the ones for zirconia were 368.4±136.14, 355±159.39, and 419.2±121.36 sec for Z1, Z2, and Z3, respectively. There was a statistical difference overall (ANOVA, $p=.009$); however, there was no statistical difference within the same material (ANOVA, $p=.5$ for lithium disilicate, and $p=.56$ for zirconia). When comparing the restorative materials, zirconia crown retrieval takes approximately 100-200 sec longer than lithium disilicate one with statistical significance except for the first retrieval experiment (t-test, $p=.11$, $p=.03$ and $p=.02$ for first, second, and third retrieval, respectively).

Table 1. Er:YAG laser-assisted crown retrieval time (min).

Sample Grouping [#]	LD1	LD2	LD3	Z1	Z2	Z3
1	172	153	172	192	286	361
2	243	223	243	443	315	255
3	235	175	235	335	167	428
4	188	204	188	214	325	331
5	470	234	470	506	466	429
6	180	230	180	374	465	236
7	400	422	400	545	566	550
8	176	183	276	300	183	551
9	132	138	132	230	182	483
10	475	238	475	545	595	568
Average	267.1	220	277.1	368.4	355	419.2
Standard deviation	130.43	79.09	126.44	136.14	159.39	121.36
ANOVA All group	LD1, LD2, LD3, Z1, Z2, and Z3 $p=.009^*$					
ANOVA Within material	LD1, LD2 and LD3 $p=.50$		Z1, Z2, and Z3 $p=.56$			
t-test	LD1 and Z1 $p=.11$	LD2 and Z2 $p=.03^*$	LD3 and Z3 $p=.02^*$			

*level of significance $\alpha=.05$

[#]LD: lithium disilicate.

Z: zirconia.

1, 2, and 3: First, second, and third retrieval trials

min: minute.

Table 2. Maximal temperatures (°C) during Er:YAG laser irradiation.

Sample Grouping	LD1	LD2	LD3	Z1	Z2	Z3
1	25	22.7	24.9	21	21.1	19.6
2	23.7	23.7	26.8	21.4	24.2	22
3	26.5	28.6	25	22.8	25	21.2
4	27.3	23.6	23.2	20.5	27.8	21.7
5	22.8	24.9	23.4	22.5	23.8	22
6	24.1	25	24.1	23.2	22.7	22
7	22.4	23.5	22.1	24.6	23.5	22.6
8	22.1	28.2	25.3	24	23.9	21.5
9	24.1	24.9	25	24.6	25	22.4
10	21.5	23.5	21.9	24.2	23.3	24.9
Average	23.95	24.86	24.17	22.88	24.03	21.99
Standard deviation	1.89	2.01	1.53	1.51	1.74	1.32
ANOVA All group	LD1, LD2, LD3, Z1, Z2, and Z3 p=.006*					
ANOVA Within material	LD1, LD2 and LD3 p=.52			Z1, Z2, and Z3 p=.02*		
t-test	LD1 and Z1 p=.18		LD2 and Z2 p=.34		LD3 and Z3 p=.003*	

*level of significance $\alpha=.05$

#LD: lithium disilicate.

Z: zirconia.

1, 2, and 3: First, second, and third retrieval trials.

The maximum temperatures for lithium disilicate were $23.95.1\pm 1.89^{\circ}\text{C}$, $24.86\pm 2.01^{\circ}\text{C}$ and $24.17\pm 1.53^{\circ}\text{C}$ for LD1, LD2 and LD3, respectively. The maximum temperatures for zirconia were $22.88\pm 1.51^{\circ}\text{C}$, $24.03\pm 1.74^{\circ}\text{C}$, and $21.99\pm 1.32^{\circ}\text{C}$ for Z1, Z2, and Z3. There was a statistical difference overall (ANOVA, $p=.006$) and within the zirconia group (ANOVA, $p=.02$), while no statistical difference was noted within the lithium disilicate group (ANOVA, $p=.52$). The maximum temperature was lower in the zirconia group compared to the lithium disilicate group; however, there was only statistical difference in the third retrieval experiment (t-test, $p=.18$, $p=.34$, and $p=.003$ for first, second, and third retrieval, respectively).

Changes in abutment surface area and cement gap as a result of additional tooth preparation prior to the third crown retrieval experiment are summarized in **Table 3**. The abutment surface area played an important role in the retrieval time in all cases ($r=0.67$ to $r=0.86$). In terms of retrieval time, both materials demonstrated similar correlations. The larger surface area was positively correlated to the longer retrieval time. The cement gap played little to no role in the zirconia group ($r=0.2$), while in the lithium disilicate group, the larger cement gap correlated with the faster retrieval time ($r=-0.43$). In terms of temperature, the two materials behaved in the opposite direction with the weaker correlation compared to the retrieval time. Increasing the abutment surface reduced the temperature in the lithium disilicate group ($r=-0.45$ and $r=-0.48$), but the opposite was seen in the zirconia group ($r=0.56$ and $r=0.69$). The width of the cement gap had almost no role in the lithium disilicate group ($r=0.2$), while the increased cement gap weakly increased the temperature in the zirconia group ($r=0.38$).

Table 3. Effects of tooth modification on retrieval times and temperature.

Sample, Grouping, and Surface Area/Cement Gap	Abutment Surface LD1 (mm ³)	Abutment Surface LD3 (mm ³)	Cement Gap LD3 (μm)	Abutment Surface Z1 (mm ³)	Abutment Surface Z3 (mm ³)	Cement Gap Z3 (μm)
1	127.67	119.75	394	133.81	125.69	504
2	179.7	164.02	297	150.22	125.03	210
3	152.55	122.87	360	138.57	124.54	359
4	141	133.89	362	136.36	120.96	282
5	226.38	209.80	277	182.76	160.93	251
6	161.14	146.33	251	150.72	133.90	301
7	218.57	209.31	335	193.97	173.70	291
8	130.92	117.32	385	171.32	149.56	331
9	131.21	121.22	407	136.45	122.48	302
10	173.66	155.30	317	202.87	186.48	366
Average	164.28	149.98	338.5	159.705	142.33	319.7
SD	35.54	35.18	52.26	25.99	23.91	79.89
Pearson Correlation						
Each Factor and Retrieval Time	0.84	0.74	-0.43	0.86	0.67	0.20
Each Factor and Retrieval Temperature	-0.45	-0.48	0.20	0.56	0.69	-0.38

Visual examination of the crown and abutment tooth showed minor cement ablation and no visual cracks or damage to the material or tooth. The SEM analysis was made for one sample from each material group after each treatment (**Fig 3 and 4**). In the lithium disilicate and zirconia samples from all three experiments, some remaining cement particles were noted, however no noticeable surface damage, microcracks, or any other change was visible on the surface of teeth and crowns. Note that an additional lithium disilicate specimen was added and irradiated based on the protocol proposed by Rechmann et al and used as the control.[15]

Figure 3. SEM analyses of lithium disilicate crowns. SEM of the cameo surface of lithium disilicate at the 1st (LD1), 2nd (LD2), 3rd (LD3), and a control of higher laser setting based on Rechman el at[15].

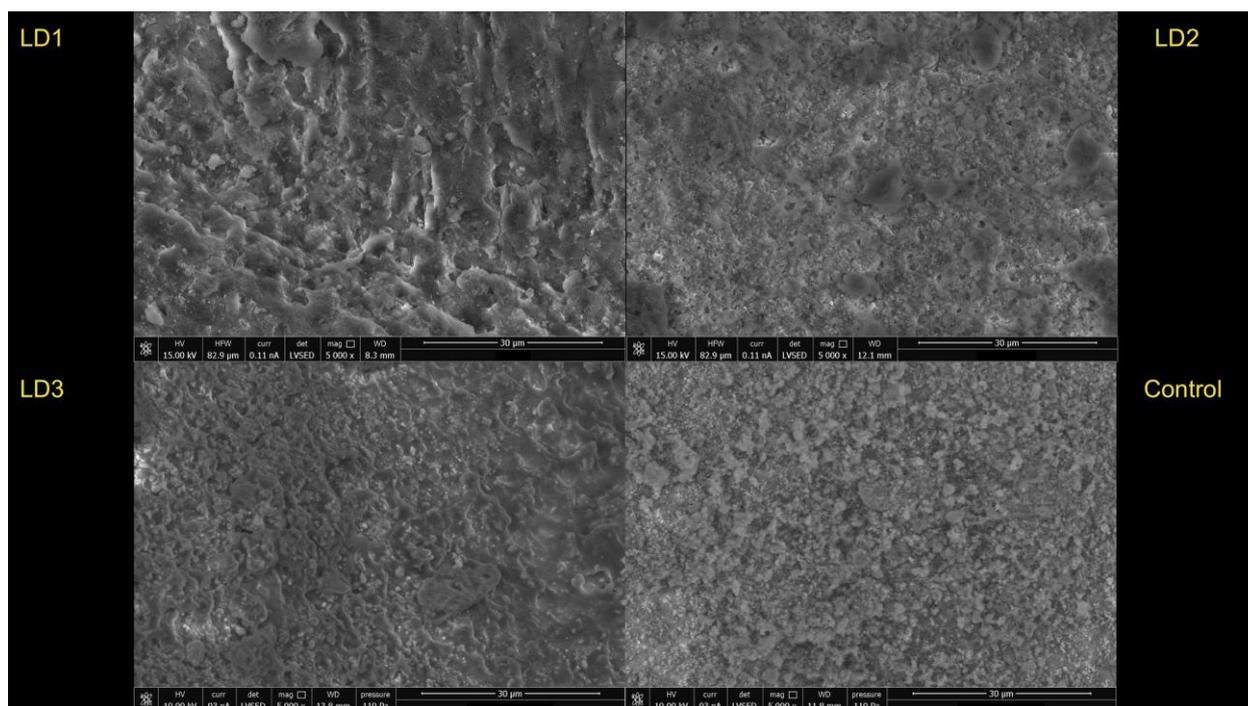
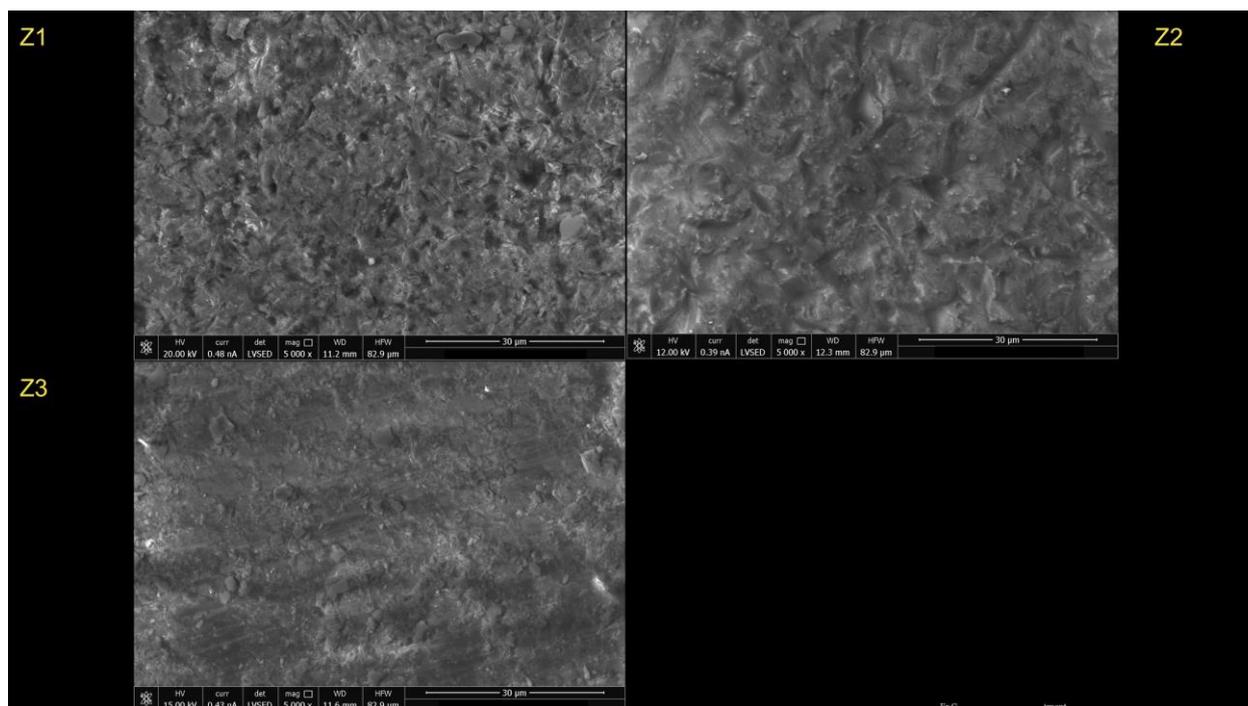


Figure 4. SEM analyses of zirconia crowns. SEM of the cameo surface of lithium disilicate at the 1st (Z1), 2nd (Z2), and 3rd (Z3).



4. Discussion

While some clinical reports and research on a non-invasive retrieval of all-ceramic crowns such as lithium disilicate and zirconia using Er:YAG laser exist in literature, there is little information on the different responses to laser-assisted crown retrieval from various ceramic materials. The results of this study highlighted the fact that crowns made from different ceramic materials behave differently when Er:YAG laser is used for their retrieval. As expected, lithium disilicate crowns are

easier to retrieve than zirconia crowns. The time required to retrieve a lithium disilicate crown on average ranges from 3 min 40 sec to 4 min 37 sec. The time required to retrieve a zirconia crown on average ranges from 5 min 55 sec to 6 min 59 sec. Zirconia crowns therefore take 2 to 3 min longer to retrieve. These retrieval times align with findings from previous studies with the same laser settings.[23,24] The retrieval times for these natural teeth are slightly higher than retrieving a zirconia crown from zirconia abutment, which are approximately 5 min 15 sec to 5 min 20 sec for the first time cementation and the repeated cementation.[25] This perhaps is a result of denser crystalized material of zirconia compared to less crystalized lithium disilicate. Furthermore, based on the study by Al-Juaila E et al[26] glass-ceramics (Emax) show higher translucency values than crystalline based ceramics (zirconia) which can explain the results of this study. In theory, the laser can penetrate through lithium disilicate better than zirconia.[26] This is reflected in longer retrieval time as well as 1°C to 2°C lower pulpal temperatures in the zirconia compared to the lithium disilicate group. It is interesting to note here that even the highest recorded temperature of ~28°C in the pulpal chamber is still considered safe.

The increase in pulpal temperature within 5.5°C could cause irreversible damage to the pulp tissue;[27] however, temperature lower than 30°C is considered safe for the vitality of the dental pulp.[27–30] A rise in temperature to 50°C for 1 min on the root surfaces can cause irreversible damage to the periodontal ligament and bone that can lead to bone resorption and tooth ankylosis.[31,32] For both materials examined in this study, the temperature rises during crown retrieval using Er:YAG laser irradiation appear not harmful to the dental pulp or adjacent tissues. This study demonstrated that both lithium disilicate and zirconia crowns can be reused without compromised structural properties following re-retrieval with Er:YAG laser. These findings are consistent with previous observations on implant crowns.[23,24] The Er:YAG laser appears to have little or no effect on lithium disilicate material.[33,34] The laser settings used here appear to be too low to alter the structure of lithium disilicate or zirconia.[23,24,35–37]

The goal of our study was also to achieve minimal retrieval time at the lowest possible settings to avoid potentially harmful temperature increase and irreversible damage to the tooth substance. Various authors have proposed a wide range of laser settings for debonding of restorations. While trying to determine optimal efficiency with safe parameters, the pilot experimented with a higher laser setting from a published protocol for retrieval of zirconia crowns (590 mJ, 10 Hz)[15,22] which resulted in macroscopically noticeable significant damage to the tooth. However, no damage was seen by SEM in any of the specimens. The settings used in this study therefore represent safe and efficient laser settings for retrieval of lithium disilicate and zirconia crowns from natural teeth similar to the ones from implant abutments.[25] One difference was noted between the tooth and implant abutments; there seemed to be more cement left inside the zirconia crown retrieved from an implant abutment in the previous study[25] compared to those retrieved from the teeth. It is possible that the cement may adhere to natural tooth structure better than to the implant abutment made of zirconia.

Unique to this study, the third crown retrieval attempt was made after some adjustment of the tooth. This was intended to simulate a clinical situation when a dentist may need to adjust the abutment tooth to refresh the dentin to optimize bonding, to remove staining or dental caries, to remove residual cement, or to replace a part of missing tooth structure. The increased cement gaps proved to have little effect on the crown retrieval time or the temperature in the pulpal chamber. Larger abutment surface areas appear to have a positive relationship with the crown retention and therefore translate into the longer retrieval time. This implies that the most important factor for crown retention is the remaining bonding surface area of the abutment tooth structure.

There are some limitations to this study. First, the teeth selected for this study had good tooth structure and therefore allowed for an ideal preparation for a crown. In reality, teeth needing crowns have less optimal tooth structure rendering preparations less ideal which may affect crown removal time. Second, attempts were made to simulate the oral cavity using a typodont mounted in a manikin head. In a live patient, cheeks and tongue can hinder the optimal access and direction of the laser irradiation. It may also be more challenging to get access and secure a crown tapping instrument at crown margins and at optimal angles. Finally, only one cement was used in this study, different

variations of cements and cementation protocols may alter the retrieval results. Future studies should focus on in vivo experiments to evaluate the retrieval time, different cementation protocols, challenges and possibly patient's perceptions.

5. Conclusions

Lithium disilicate and zirconia crowns can be retrieved without any material or tooth damage using an Er:YAG laser. The retrieval time is longer for zirconia with lower temperature increases compared to lithium disilicate crowns. The pulpal temperature resulting from the laser irradiation appears to be within the physiological limit and likely has no adverse effect to the dental pulp or surrounding tissues. Er:YAG laser can be used safely and effectively for retrieval of common all-ceramic crowns.

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Author Contributions

Conceptualization: Janina Golob Deeb, Sompop Bencharit, Kinga Grzech-Leśniak

Data curation: Sompop Bencharit, Kinga Grzech-Leśniak, Lenart Skrjanc, Domen Kanduti

Formal analysis: Sompop Bencharit, Kinga Grzech-Leśniak, Jacek Matys

Investigation: Janina Golob Deeb, Sompop Bencharit, Kinga Grzech-Leśniak, Domen Kanduti, Lenart Skrjanc

Methodology: Janina Golob Deeb, Sompop Bencharit, Kinga Grzech-Leśniak, Domen Kanduti, Lenart Skrjanc

Project administration: Sompop Bencharit

Visualization: Sompop Bencharit, Lenart Skrjanc, Domen Kanduti

Writing – original draft: Sompop Bencharit, Janina Golob Deeb

Writing – review & editing: Sompop Bencharit, Janina Golob Deeb, Kinga Grzech-Leśniak, Domen Kanduti, Jacek Matys

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