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Non-Invasive Retrieval of Prefabricated Zirconia Crowns with Er,Cr:YSGG Laser from Primary and Permanent Teeth

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Non-Invasive Retrieval of Prefabricated Zirconia Crowns with Er,Cr:YSGG Laser from Primary and Permanent Teeth

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

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Abstract

NON-INVASIVE RETRIEVAL OF PREFABRICATED ZIRCONIA CROWNS WITH ER,CR:YSGG LASER FROM PRIMARY AND PERMANENT TEETH

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Purpose: Compromised tooth structure on permanent and deciduous teeth in the pediatric population is increasingly being restored with tooth-colored prefabricated zirconia crowns. These restorations may need to be removed or replaced with permanent crowns. The purpose of this in vitro study was to explore the use of an Er,Cr:YSGG laser for removal of prefabricated zirconia crowns cemented with RMGI as a non-invasive alternative to rotary instruments.

Methods: Thirteen permanent and 12 primary molars were prepared to dentin and prefabricated zirconia crowns were passively fitted and cemented with two resin modified glass ionomer cements. The irradiation parameters for ErCR:YSGG were 4.5 Watts, 15 Hertz, 20 Water, 20 Air; 5 Watts, 15 Hertz, 50 Air, 50 Water with the Turbo Mx9 Handpiece. The experiment was repeated three times for permanent teeth and twice for primary teeth. The debonding time, laser settings and pulpal temperature changes were tested and recorded for all groups. Data were analyzed using repeated measures ANOVA with Tukey's adjusted post hoc pairwise comparisons t-test.

Results: The average time for permanent molar laser-assisted crown removal was 3 minutes and 47.7 sec. The average time for primary molar crown removal was 2 minutes and 5 sec. The mean temperature changes for permanent teeth were 2.48 (SD=1.43)°C and increased by 3.8°C for higher laser setting; and 3.14 (SD=1.88)°C for primary teeth. The time to debond was significantly positively correlated with inner surface area, inner volume, outer volume, and the cement volume.

Conclusion: The Er,CR;YSGG Erbium laser proved to be an effective, non-invasive tool to remove prefabricated zirconia crowns cemented with RMGI cements and should be considered as a viable alternative to rotary instrumentation.

Introduction

Dental caries continues to be the most prevalent chronic childhood disease.[1] Many interventions such as water fluoridation, fluoride toothpaste, fluoride varnish have helped combat smooth surface-cavities but the incidence of caries in pits and fissures have not kept with this pace allowing for caries progression and subsequent need for treatment.[2] Caries can greatly impact a child's well-being, resulting in infection, poor nutrition, missing school and negatively impacting learning, and decreased overall quality of life.[3] Over time, clinical dentistry has evolved to treat this disease by removing the caries and restoring teeth with materials such as amalgam, composites, stainless steel crowns and most recently, zirconia crowns.

The stainless steel crown (SSC) has long been considered as the "gold standard" for restoring carious primary molars.[4] The crown is designed in a way that mimics the anatomy of both the primary and permanent teeth. In primary teeth, the cervical third of the crown presents with the greatest convexity which serves as the retention point. Stainless steel crowns are flexible enough to spring into and be retained by this bulge/undercut area. Primary teeth have proportionately thinner enamel and dentin making them prone to caries attack. Additionally, they have large pulp horns requiring calculated cavity preparation design. Like the primary molars, the permanent stainless steel crown also resembles the anatomy of the first permanent molar and gains retention from the cervical margin area. Primary SSCs have been indicated in the following situations:

following pulp therapy; for restorations of multi surface cavities and for patients at high risk for caries; teeth with developmental defects; fractured teeth; teeth with extensive wear; and serve as the abutment for a space maintainer. In permanent molar teeth, the following indications can warrant a stainless steel crown: interim restoration of a traumatized or severely broken down tooth until a permanent restoration can be done; financial considerations, SSCs typically cost less than porcelain-fused to metal (PFM) or zirconia counterparts; to restore the occlusion and reduce any sensitivity from dysplasias; and for restoring partially erupted molars that require full coverage.[5]Following the eruption of permanent teeth, complete calcification continues for two additional years, rendering the teeth especially susceptible to caries formation during this time. Moreover, permanent teeth often have incompletely formed coalesced pits and fissures with or without hypoplasia where dental plaque can accumulate at the base of the defect, sometimes contacting exposed dentin[6] For years, SSCs have been utilized to restore teeth presenting with cervical demineralization, and developmental defects (e.g. hypoplasia, molar-incisor hypomineralization, dentinogenesis imperfecta). Multiple longitudinal studies have demonstrated the superiority over amalgam restorations in restoring primary molars with multi-surface involvement.[7,8] In 2015, a systematic review stated that preformed pediatric crowns are the most appropriate restorative technique when compared to traditional measures[9] Stainless steel crowns are also utilized to restore permanent molars that have been either compromised or have been treated with a root canal, up until the patient stops growing. Once the growth stops, the teeth can then receive a permanent, indirect full-coverage restoration.

During the past 50 years, mainly due to local anesthetics and improved dental materials, the trend in dental treatment has evolved from removal to rehabilitation. Over the last 20 years, there has been an increased demand by parents for highly esthetic restorations to treat their child's teeth. This esthetic concern trend disagrees with stainless steel crowns and favors the addition of zirconia crowns to the pediatric dentist's armamentarium. Zirconia is a crystalline dioxide of zirconium that has mechanical properties similar to those of metals, and its color is similar to that of teeth. Through companies such as Sprig and NuSmiles, ready-made zirconia crowns are now available for both, primary incisors, molars and permanent molars.[10] *(Figure 1)*

Figure 1: NuSmile ZR Zirconia Crowns

Zirconia crowns require more circumferential tooth reduction for proper fit and placement compared to SSCs. The indications for zirconia crowns are usually the same as for SSCs.[11] Stainless steel crowns have better retention, but recent studies demonstrate that zirconia crowns allow for better gingival health and less plaque accumulation, coupled with vastly better esthetics.[11,12] As zirconia crowns require greater tooth reduction (minimum 1.5-2mm) and a passive fit, cementation is critical for their longevity.[13] Strong cement bond between a crown and tooth however, can present a challenge when the restoration needs to be removed.[14] Zirconia crowns are often removed by sectioning using a diamond or tungsten carbide bur, which can be time consuming and stressful for the patient.[15–17] It is often difficult to differentiate between the tooth and the tooth-colored restoration when sectioning with high-speed burs, leading to unintended iatrogenic tooth damage.[18]

Erbium family lasers have been reported to address this removal concern. The term LASER stands for light amplification by stimulated emission radiation. The light admitted by erbium lasers is well-absorbed by hydrated biological tissues, including dental hard tissues. Studies have proposed that erbium laser's light is transmitted through the material and selectively absorbed by water molecules and residual monomers in the resin cements, resulting in reduced bond strengths. This technology has been successfully applied for ceramic orthodontic brackets debonding from tooth surfaces.[18–20] This process of laser energy moving through the ceramics and vaporizing the molecules in the resin cement (water molecules or residual monomers) is called thermal ablation and involves vaporization followed by hydrodynamic ejection.[21]

It is commonly believed that dental pulpal tissues are susceptible to high temperatures. In general, when tissue is raised to a temperature of 45°C, no essential irreversible tissue damage occurs. Between 45 and 50°C, enzymatic changes occur and edema develops. Lastly, heating to more than 60°C for more than a few seconds causes coagulation (i.e., a denaturation of the tissue protein) [22] Moreover, Reichmann et al. evaluated temperature changes in the pulpal temperature during laser debonding of all-ceramic crowns using an Er:YAG laser. They used a 560 mJ/pulse and the temperature rise in the pulp chamber from irradiation averaged 5.4°C ± 2.2°C with the higher temperatures only occurring when sufficient air/water cooling from a dental syringe is inappropriately applied.[16] A study by Zach and Cohen on Macaca Rhesus monkeys found temperature rises above 5.5°C (10°F) can cause irreversible pulp damage.[23] Given this low value, Baldissara et al. repeated Zach and Cohen's experiment on 12 healthy teeth that were being extracted for functional or orthodontic reasons. Using an electrical heat source, the evaluated thermal increases ranged from 8.9-14.7 °C on healthy dental pulps. Their preliminary results indicate average increases of 11.2 °C on vital bicuspids do not damage the pulp because no signs of inflammation and no reparative processes were detected in the test samples within 68-91 days after treatment. They concluded heat does not appear to be a major factor of injury and that the main cause of postoperative inflammation or necrosis of the pulp is probably linked to dentin injury.[24] Gurney et al. compared the time required to remove lithium disilicate crowns using an erbium laser and high-speed with diamond burs and showed that laser assisted removal can be done in 60-90 seconds, compared with approximately 6 minutes required with high-speed diamond burs.[25] Recently published data about safely removing lithium disilicate crowns from zirconia implant abutments with Er:YAG laser, give evidence of using this technique as a viable alternative to rotary instruments.[26]

As stated above, Erbium lasers have become an established tool in dentistry with the main goal of being able to selectively ablate hard and soft tissues in a controlled manner without adversely affecting adjacent tissues. The two most commonly used lasers are the Er:YAG (erbium-doped yttrium aluminum garnet laser, erbium YAG laser) and Er,Cr:YSGG (erbium,chromium: yttrium-scandium-gallium-garnet). Both lasers use solid state crystals, YAG or YSGG, doped with erbium ions (Er3+) as their active materials and both lasers are pumped by a pulsed broad band flashlamp.[27] The two Erbium lasers have two subtle but very important differences. One is the laser wavelength, the other is in the technology they use to energy the flash lamps. The Er:YAG laser has a wavelength of 2940 nm and the Er,Cr:YSGG's wavelength is 2790nm.[28] These wavelengths allow them to exhibit the highest absorption of all infrared lasers in water and hydroxyapatite, thus making them optimal tools for "drilling" in enamel, dentin and composite fillings, the hard and soft dental tissues.[29,30]

Additionally, Er,Cr:YSGG laser's flash lamp is energized by PFN (Pulse Forming Network) pumping.[31] A conventional method of energizing a flashlamp consists of discharging a pulse forming network through the flashlamp. The pulse forming network is made up of capacitators (C) to store electrical energy and inductance (L) to limit the discharge current into the flashlamp load (R).[27] Pulse Forming Network (PFN) pulses are bell shaped and mostly of a fixed duration. The pulse generating technology of the Fotona Er:YAG dental laser is of VSP (Variable Square Pulse) pumping.[30] Though seemingly miniscule, this variation in pulse shape has drastic effects. The VSP pulse generates a pulse where the average power and peak power is nearly the same, which cannot be said for the PFN pulses. The PFN pulses are more asymmetrical and the pulse power is not constant during the pulse duration and the exact pulse duration is not defined.[27] Variable Square Pulse pumping utilizes a switching transistor, where a simple on or off of the transistor controls the current in the flashlamp. This allows VSP pumping technology to be conveniently controlled over a wide range of pulse durations, leading to more predictable tissue ablation.[29]

Wavelength is another major component for laser suitability in dentistry. As stated above, both the Er:YAG and Er,Cr:YSGG laser wavelengths operate within the major absorption peaks for water, making them suitable for hard-tissue ablation. In contrast, CO2 and Ho:YAG show significantly less absorption in water and are not ideal for dental use. There is a 300% difference between absorption coefficients of Er,Cr:YSGG (400mm^{-1}) and Er:YAG (1200 mm^{-1}) due to the different wavelengths. Given the water content in the tissue, this absorption coefficient for the Er:YAG lasers aligns with 150mm^{-1} in enamel and 200mm^{-1} in dentin, allowing the laser to penetrate approximately 7 micrometers in enamel, and 5 micrometers in dentin. With the Er,Cr:YSGG absorption coefficients being 3 times lower, the Er,Cr:YSGG laser wavelength penetrates deeper, 21 micrometers in enamel, and 15 micrometers in dentin. Because of the higher absorption corresponding with the larger wavelength, the Er:YAG laser has a smaller penetration depth, thus requiring less energy and less time to ablate the tissue. The Er:YAG laser is more efficient with tissue ablation and exerts less effects on the underlying tissue compared to the Er,Cr:YSGG laser which takes three times longer to deliver three times more energy to heat the three-times thicker area up to the desired temperature for ablation.[27]

In summary, one of the major clinical advantages of using the Er:YAG laser is its ability to ablate both hard and soft tissues with minimal thermal damage.[32] Aside the differences in wavelengths and technology used to energize the flashlamps, both Erbium lasers supplement and improve the dentist's armamentarium.[27]

The following information pertaining to Biolase was taken from Biolase, Inc. North America.[33] Waterlase *(Figure 2)* is a medical device company specializing in the manufacturing and marketing of proprietary dental laser systems that allows dentists a multitude of procedure options. BIOLASE is a laser company widely used in dental practices. Once such laser is the Waterlase iPlus which is the market's best-selling all-tissue laser. This Er,Cr:YSGG laser tissue cutting system has both hard- and soft-tissue cutting ability. Given its advanced water atomization technologies, a dentist can cut and modify hard-tissue, while also removing soft-tissue for procedures such as incision, excision, ablation and coagulation. Additionally, Waterlase can be used for endodontic and periodontics procedures. For hard-tissue, an YSGG solid-state laser energizes to a user-controlled distribution of atomized water droplets and hydrated surface of hard tissue. The water that is present in the target tissue absorbs this laser radiation, with resultant explosive molecular expansion and subsequent ablation of hard tissue. All while the water in the spray provides cooling and hydration of the target tissue and prevents thermal damage. Additionally, for soft-tissue this same optical energy is targeted to the desired location with water for cooling and hydration to remove tissue, ablate tissue or without water for coagulation.

Figure 2: Biolase Waterlase iPlus[33]

Biolase Waterlase iPlus us indicated for the following procedures: Hard tissue (including cavity preparations, caries removal, hard-tissue surface roughening or etching, enameloplasty, excavation of pits and fissures for placement of sealants); Root-canal preparation, enlargement, debridement and cleaning; Endodontic surgery with root amputation, flap preparation, window access, apicoectomy, root-end preparation, removal of pathological tissues and hyperplastic tissues; Bone surgery including cutting, shaving, contouring and resection of oral osseous tissues and osteotomy; Laser periodontal procedures including full, partial and split-thickness flaps, soft-tissue curettage, tissue resection, sulcular debridement, osteoplasty and osseous recontouring, ostectomy, osseous crown lengthening, new attachment of cementum to the periodontal ligament to the root surface, and calculus removal; Soft tissue indications including pulpal tissues consist of incision, excision, ablation and coagulation of oral soft-tissues, including: incisional and excisional biopsies, exposure of unerupted teeth, fibroma removal, flap preparation, frenectomy and frenotomy, gingival troughing, gingivectomy, gingivoplasty, gingival excision and incision, hemostasis, implant recovery, incision and drainage of abscesses, laser soft-tissue curettage of the post-extraction tooth sockets and the periapical area during apical surgery, leukoplakia, operculectomy, oral papillectomies, pulpotomy, pulp extirpation, pulpotomy as an adjunct to root canal therapy, root canal debridement and cleaning, reduction of gingival hypertrophy, removal of pathological tissues, soft-tissue crown lengthening, treatment of canker sores, herpetic aphthous ulcers of the oral mucosa and vestibuloplasty, and lastly, Root Canal Disinfection after endodontic instrumentation.

The same clinical judgement must be utilized as with traditional procedures. Caution must be taken in procedures such as, allergy to local or topical anesthetics, heart disease (e.g. pacemakers, implantable defibrillators), lung disease, bleeding disorders, or an immune system deficiency. Medical clearance from the patient’s physician is advisable when doubt exists regarding treatment. Eyewear must be worn by all people inside the operatory. This eyewear must comply with the 2780nm wavelength, OD3 or greater (OD 3+). Although most cases do not require anesthesia, anesthesia can be provided if patients are experiencing signs of pain or discomfort. Treatment should always be started with the lowest power setting for the specific tissue and procedure and be increased as required. All hard-tissue procedures should be done with the appropriate air-water cooling or tissue thermal damage can occur. The long pulse setting (700 µs) is indicated only for soft-tissue procedures. Extreme caution should be used in areas with low visibility such as third molars, etc. to avoid any nerve or vessel damage. Care should be taken to not direct air or spray toward tissues that may trap air or water because an air embolism could occur (e.g. soft-tissue pockets, third molars and sublingual and submandibular spaces. Avoid curved canals for root canal therapy given the tip may perforate canal walls. Effective root canal disinfection should be done with correct tip RFT2 and RFT3, which have a 200 µm and 300 µm diameter, respectively, and come in various lengths. Lastly, no water, only air should be used with the maximum setting at (10%). Care should always be taken to avoid damaging adjacent structures. Sterile field and aseptic should be used for all procedures, especially for surgical interventions. All tissue removal should be submitted for histopathology assessment. The fiber tip should not contact hard-tissues. Hard-tissue cutting occurs in non-contact mode with the tip 0.5 mm to 3 mm off the surface (3 to 5 mm for Turbo Handpiece). Tips are brittle and can break easy. Protection should be worn due to water splashing during treatment, along with high-speed suction. Laser plume may contain visible tissue particles; again high-speed suction should be used to prevent infection from the laser plume generated by vaporization of virally or bacterially infected tissues. Lastly, avoid directing the laser toward amalgam, gold or other metal surfaces, cements, or other similar filling materials. This may damage the tip and delivery system.[33]

Prefabricated zirconia crowns are being more frequently used in pediatric dentistry and easing their removal by using erbium laser to debond them from the tooth would offer a great advantage in clinical practice.

To date, no studies have been conducted to study the use of Er,Cr:YSGG laser for removal of prefabricated zirconia crowns from primary teeth. The aim of this study was to analyze the time, settings and laser parameters that are efficient and safe for the non-invasive retrieval of prefabricated zirconia crowns with Er,CR:YSGG laser on the extracted primary and permanent teeth.

Methods

Twelve primary (G1-BC1, N=12) and 13 permanent teeth (G2-BC1, N=13) were prepared and restored with prefabricated all-ceramic zirconia crowns (Nusmile®, Houston, USA) cemented with resin modified glass ionomer (RMGI) cement (BioCem, NuSmile®, USA). Following debonding, the crowns and teeth were cleaned of residual cement and crowns were recemented back with BioCem cement on primary (G1-BC2, N=12) and permanent (G2-BC2, N=13) teeth. The group of 12 permanent teeth, one was removed for SEM analysis, (G2-RX1, N=12) was recemented a third time with another RMGI (RelyX. 3M ESPE, St. Paul, Minn., USA). One primary tooth from group G1-BC1 and two permanent teeth from groups G1-BC1 and G2-BC2 were withheld for SEM analysis.

For maximized retention, the NuSmile crown system includes pink Try-in crowns for fitting.[34] Therefore, the cemented crown is not contaminated with blood or saliva prior to cementation nor can phosphate bonds react with cement on the intaglio surface of the crown. Given this was in-vitro study, devoid of any blood or saliva, the pink Try-in crowns were not utilized.

In this study, two RMGI cements were used: BioCem and RelyX Luting Plus Automix Cement. Biocem is a recommended crown manufacturer product, while RelyX is commonly used for posterior crown cementation in pediatric dentistry. A tack cure option allows for shortened clean up time. Two setting reactions consist of an acid-base reaction between the glass and polycarboxylic acid and a free radical polymerization of the methacrylate polymer and HEMA

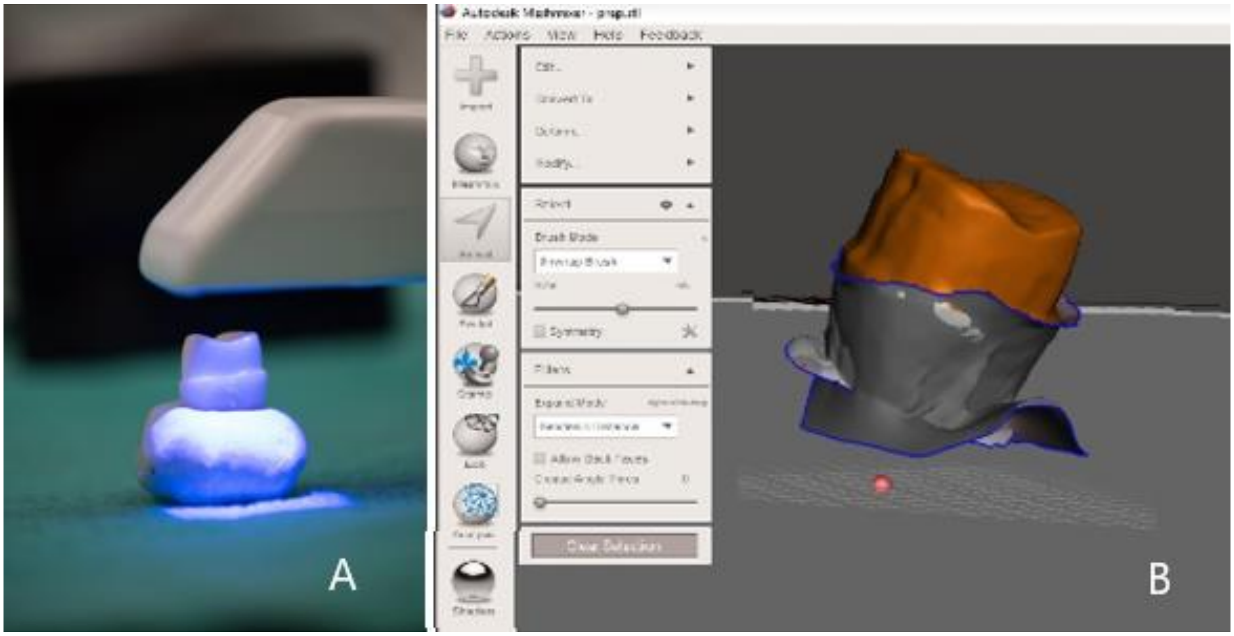
(2-hydroxyethyl methacrylate). Additionally, it is moisture tolerant, and as with other RMGIs has resin bond strength coupled with fluoride release.[35] BioCem is a bioactive, dual-cure RMGI that releases phosphate, calcium and fluoride. BioCem has the ability to form hydroxyapatite that integrates with and replenishes tooth structure. With low water absorption and solubility, Biocem is claimed to have a high washout resistance.[36] Overall, bioactive materials stimulate hydroxyapatite formation on integration into tooth structure. Like RMGIs, they also exhibit minimal microleakage and bond well to zirconia.[37] Aside from their unique properties, they contain water molecules and residual monomers in the resin cements, resulting in reduced bond strengths when irradiated by the erbium laser's light.

Primary and permanent teeth planned for removal were extracted and stored in saline. Before preparation, all teeth were analyzed for remaining non-carious tooth structure for inclusion in the study. Teeth that had either a fractured crown or roots, gross caries, or presented with previous restorations were not included in the study.

The teeth were reduced and prepared for all-ceramic restorations following the manufacturer's instructions.[34] First, 1-2mm of occlusal reduction was done with a 368-023 football-shaped coarse diamond bur (Henry Schein®). Then, the interproximal sites and entire clinical crowns of the teeth were reduced by 20-30% with a 169L taper fissure plain carbide bur (Henry Schein®). To establish a chamfer/feather-edge margin the 169L and an 850-010 needle-diamond were utilized (Henry Schein®). Lastly, all the line angles of the preparations were rounded with the needle-diamond bur and football-shaped coarse diamond bur to remove any sharp angles and provide for a slightly tapered preparation that would allow for the zirconia crown to "passively fit".[34]

Once the preparations were completed, each tooth was sequentially numbered and scanned using computer-aided design (CAD) technology. *(Figure 3A)* The scanned file was then exported to MeshMixer© (Autodesk, Inc.) software where the volume and surface area of each preparation were calculated. *(Figure 3B)*

Figure 3: Scans Showing Computer-Aided Design (A) and Meshmixer© Analysis (B)



Following scanning, NuSmile® zirconia crowns were tried-on for the most intimate fit while still being “passive”, per manufacturer’s instructions. (NuSmile®, USA) Once the zirconia crown for each tooth preparation was finalized, the crowns were dried with cotton gauze until no visible water was left on the crown. Biocem was then bled from the syringe, an auto-mix tip was attached and the cement was dispensed into the crowns within the 60 second “working time”. The crowns were then placed over the teeth and properly seated. Finger pressure was then utilized to stabilize the crown for approximately 20 seconds. Using a curing light (Henry Schein®, Maxima LED), each crown was flash cured for 5-10 seconds using a (800-1200 mW/cm^2) curing light on both the facial and lingual aspects of the crown. Since the crowns were cemented “in-hand”, interproximal cement removal was not done, nor was excess cement removed after the initial flash cure. *(Figure 4)* Lastly, the zirconia crowns were light cured for an additional 10 seconds minimum each on, but not limited to, both the facial and lingual surfaces.[38]

Figure 4: Image Showing Light Cured Zirconia Crown on Extracted Tooth Permanent Tooth Before Laser Debonding

After cementation, the crowns were scanned using CAD technology. Meshmixer© software was again utilized to calculate the cemented crowns’ surface area (mm^2) and volume (mm^3). *(Figure 5)*

Figure 5: Image Showing Meshmixer© Analysis of Cemented Crown After CAD Scan


Autodesk Meshmixer - prep.stl

Brush Mode
Unwrap Brush
Size 55
Symmetry
Expand Mode
Geodesic Distance
Allow Back Faces
Crease Angle Thres 0

All teeth were stored in moist containers (humidor) to prevent desiccation prior to attempted crown removal. The crowns were allowed to cure for 24-48 hours before retrieval was initiated.

In summary, twelve primary (G1-BC1) (N=12) and 13 permanent teeth (G2-BC1) (N=13) were prepared and cemented with BioCem. Laser removal was accomplished and excess cement was removed from the crowns and abutment teeth. The 12 primary (G1-BC2) (N=12) and 13 permanent teeth (G2-BC2) (N=13) were then recemented with BioCem and removed with the laser. Lastly, 12 permanent teeth, one removed for SEM analysis, (G2-RX1) (N=12) were recemented with Relyx and removed with the laser.

Laser Settings

This study utilized the Er,Cr: YSGG (Biolase® Waterlase iPlus) laser with the following settings to retrieve the primary crowns (G1-BC1): 4.5 Watts, 15 Hertz, 20 water and 20 air with the Turbo MX9 handpiece. *(Figure 6)*

Figure 6: Biolase® Waterlase iPlus Turbo MX9 Handpiece

For permanent crown removal (G2-BC1), the first set of crowns were removed with the following settings: 4.5 Watts, 15 Hertz, 20 water and 20 air. The second round of crown removal for primary teeth (G1-BC2) used the following settings: 5 Watts, 15 Hertz, 50 water and 50 air. The second (G2-BC2) and third round of permanent crown removal (G2-RX1), using RMGI (RelyX®) crowns, utilized the following settings: 5.0 Watts, 15 Hertz, 50 air and 50 water. All crown removal trials were again conducted with the Turbo MX9 handpiece. The watt, equivalent to one joule per second, indicate the "power" of the laser and the hertz indicate the unit or frequency, i.e. "pulses per second".[39] The air and water settings indicate the amount of air and water that the laser utilizes on a scale of 0-100. These settings were chosen based off of other studies that utilized lasers for crown removal with the goal of achieving minimal retrieval time, all while avoiding high settings and temperature raises that could damage the pulpal tissue, harm the tooth or make the patient uncomfortable. The irradiation time required for the crowns to become debonded was measured. To analyze if the crown could be debonded, two minutes of initial irradiation time was used, the crowns were then examined with digital manipulation and tapping instrument for crown removal to examine if crown could be removed and if debonding was achieved. If successful, the crown was removed and the procedure completed. If not successful, each crown was subjected to additional 60-second irradiation intervals until removal achieved.

Laser Debonding Procedure

The following steps describe the laser irradiation pattern for debonding the all-ceramic crowns:

The crowns were held digitally and laser irradiation was initiated on the buccal or lingual margins of the teeth. For 30 seconds the handpiece was moved in a direction from buccal to lingual in a back and forth motion keeping the irradiation fiber 2-5 mm from the crown surface and moving the handpiece from one contact point to the other. Staying at a distance from the occlusal surface prevents sparking during the debonding procedure. When the irradiation tip reached the opposite "imaginary" contact point, the movement was reversed to irradiate back to the original contact point, all while painting the buccal, lingual and occlusal surfaces with 1mm stripes. Each of the buccal, occlusal and lingual surfaces of the crown were irradiated for 30 seconds. Though no adjacent teeth were present, the interproximals were NOT irradiated in order to mimic adjacent teeth being present in the mouth. This protocol resulted in an initial 2 minutes of irradiation time and subsequent 30 second irradiation sessions, if needed.

Laser Debonding Analyzation

The following steps describe the crown retrieval pattern for debonding the all-ceramic crowns:

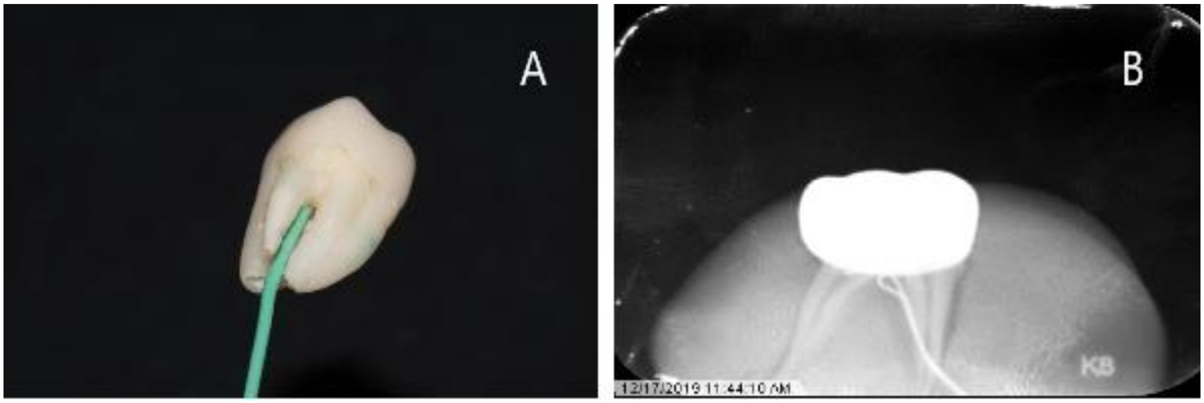
To analyze if the crown could be debonded, two minutes of initial irradiation time was used, the crowns were then examined with digital palpation for ease of removal and a crown remover was used on a benchtop to see if bebonding could be achieved. The crown remover was not placed on the interproximal surfaces, again aiming to imitate limited access if adjacent teeth are present in the mouth. If successful, the crown was removed and the procedure completed. If not successful, each crown was subjected to an additional 30 second intervals of irradiation and crown removal steps were conducted until the crown could be retrieved. The irradiation time, until the crowns were debonded, was measured in 30 second increments. After debonding, each crown and tooth were examined clinically to analyze the adherence of cement to the dentin or crown.

Measuring Pulpal Temperature

The following steps describe how the pulpal temperature of each tooth was measured:

Following crown cementation, a hole (size #4 round bur in a straight handpiece) was drilled into the furcation of each tooth *(Figure 7A)* to allow insertion of a temperature probe (Sper Scientific® 800008) into the space of the pulp. *(Figure 7B)* Before initiating crown removal, a pulpal temperature was recorded at the baseline and throughout the entire procedure at 30 second intervals.

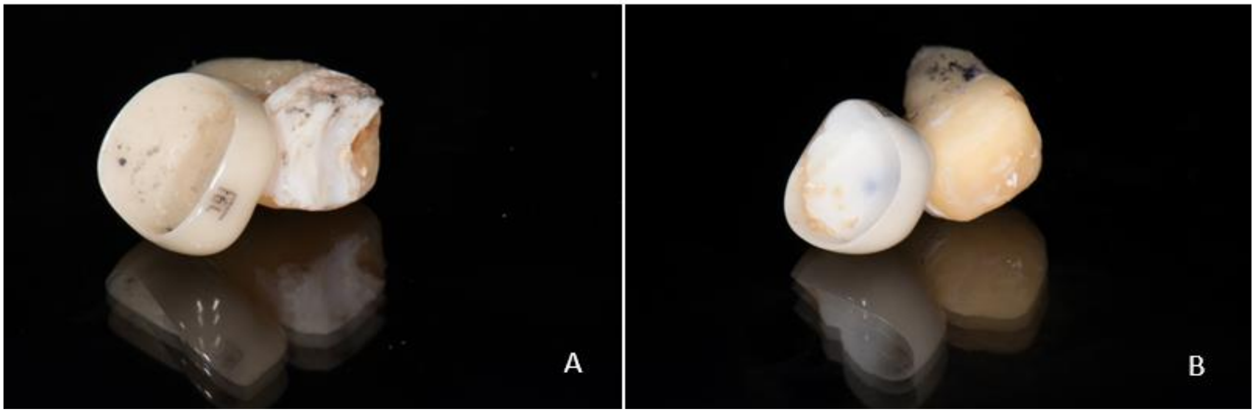
Figure 7: Photo (A) and Radiograph (B) Showing Inserted Temperature Probe into a Pulpal Chamber of the Tooth



Removal and Recementation

As previously mentioned, 12 primary teeth (G1-BC1) were prepped and cemented with prefabricated primary zirconia crowns and 13 permanent (G2-BC1) teeth were prepped and cemented with prefabricated permanent zirconia crowns. *(Figure 8B)* After the first debonding trial cycle, teeth were cleaned and crowns were cleaned with high-speed handpieces, scalers and sand-blasted, if necessary. All cement was removed from the teeth or crowns before the second trial was initiated (G1-BC2)(G2-BC2). The second trial for both primary (G1-BC2) and permanent (G2-BC2) teeth groups utilized BioCem (NuSmile®). For permanent teeth, the purpose was to explore a slightly different laser setting (recommended by laser manufacturer), lighter digital manipulation for removal of the crown (less tapping force) and to examine if laser debonding performed in the first trial would affect adhesion properties of the second recementation. *(Figure 8A)*

Figure 8: Images Showing Post Debonding of Permanent Teeth (A) and Primary Teeth (B)



Permanent teeth underwent three experimental cycles. The first two cycles used groups G2-BC1 and G2-BC2 utilized BioCem (NuSmile®) cement with slight parameter and removal protocol modifications. The third experimental cycle was then done. The third trial (G2-RX1) included cementation with another RMGI cement (RelyX, 3M ESPE, St. Paul, Minn., USA). Based on experience in clinical practice, this cement is often used for cementation of prefabricated zirconia crowns and the goal of the study was to include it and examine the parameters for its debonding. 3M RelyX Plus Automix Cement, per manufacturer’s instructions.

Scanning Electron Microscope (SEM) Analysis

Scanning electron microscope analysis was conducted. Both teeth and zirconia crowns were analyzed to assess any iatrogenic damage from Er,Cr:YSGG laser crown removal.

Statistical Methods

Comparisons between deciduous and permanent teeth were compared using equal and unequal variance t-tests as appropriate. Repeated measures ANOVA with Tukey's adjusted post hoc pairwise comparisons were used to determine differences in the debond time across the two (primary) or three (permanent) debond attempts. Pearson's correlations was used to determine the association between crown metrics and the time to debond. Multiple linear regression was used to determine the relationship between time to debond and the cement volume and the ratio of the outer to inner surface area.

Results

Results

Thirteen permanent teeth, 12 in RelyX group, and 12 primary teeth were utilized in this study. Permanent teeth were debonded a total of three times and primary twice. Summary of the volume and surface area metrics for the crowns are given in *Table 1*.

Table 1: Summary Statistics for Permanent and Primary Crowns

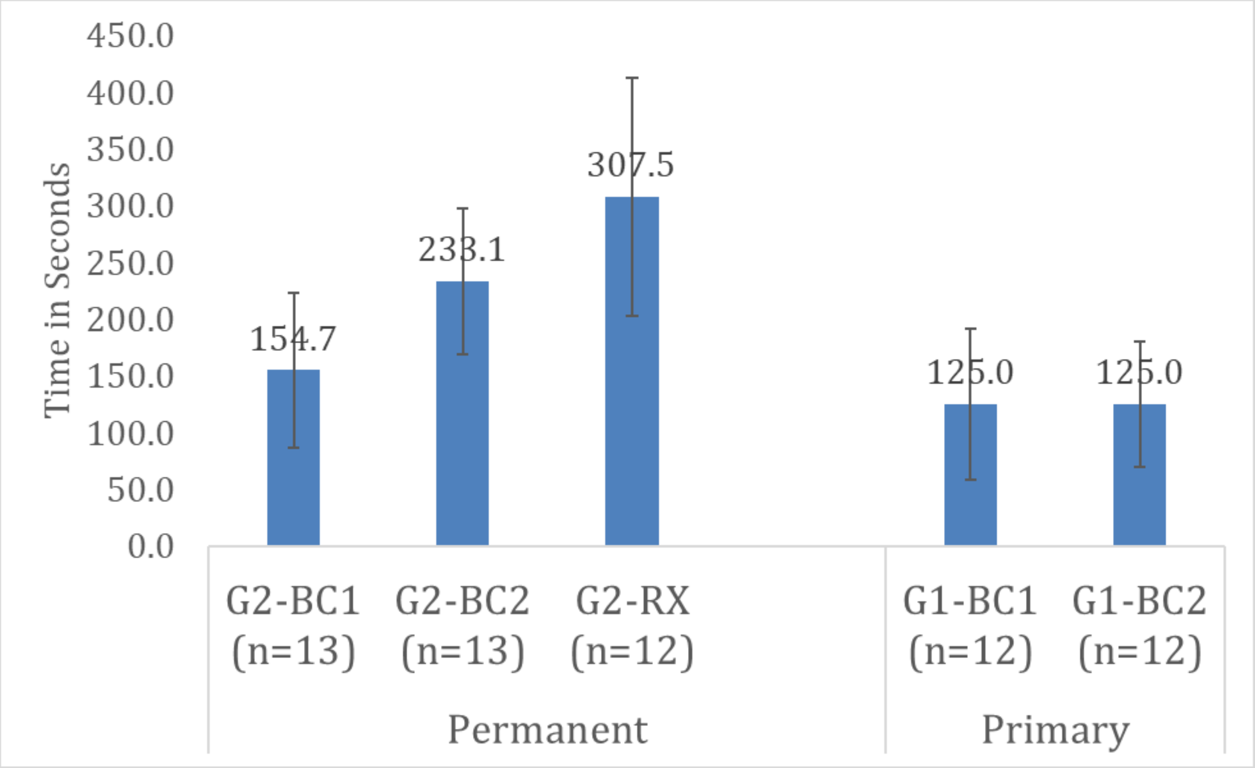
	Mean, SD	
	Permanent Teeth (n=13)	**Primary Teeth (n=12)**
Crown Volume	201.58, 31.31	93.92, 43.83
Inner surface area	168.59, 29.19	88.77, 26.85
Outer surface area	270.55, 24.85	166.31, 43.43
Ratio surface area (outer:inner)	163.41, 21.94	193.12, 33.63
Inner volume	227.5, 68.05	76.45, 40.10
Outer volume	533.52, 105.08	254.16, 102.52
Ratio volume (outer:inner)	242.91, 41.07	379.89, 166.57
Cement volume	105.95, 33.56	84.64, 45.67
Average Debond Time (all trials combined)	227.72, 99.63	125.00, 59.78

*Volume in mm^3, Surface Area in mm^2

Debonding Time

The average time for crown removal using Er,Cr:YSSG laser for permanent molars (N=13,12) was 3 minutes (min) and 47.7 sec. The average time for crown removal using Er,Cr:YSSG laser deciduous teeth (N=12) was 2 minutes (min) and 5 sec. *(Figure 9)* Permanent molars took, on average, 1 minute and 42.7 seconds longer than deciduous teeth, which was statistically significant (p<0.0001).

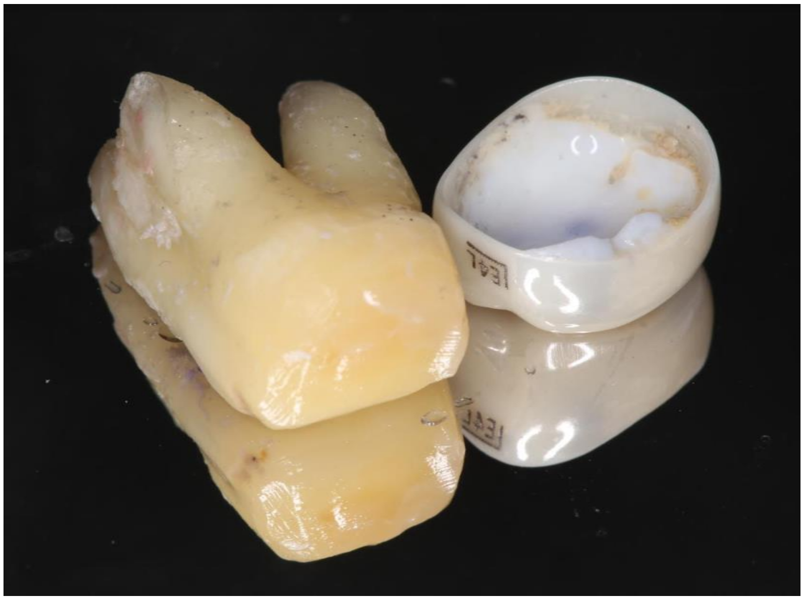
Figure 9: Graph of Average Debonding Times for Primary and Permanent Teeth (Error Bars Represent +/- Standard Deviation)



For permanent molars, there were significant differences in the debond time based on the three settings (p-value<0.0001). Debond 1 was the fastest (G2-BC1), with an average of 2:34.60, and was marginally significantly faster than debond 2 (G2-BC1)(average difference= 78.38 seconds;

adjusted p-value=0.0513). Debond 3 (G2-RX1) required the longest time (average=307.5 seconds) and was significantly more time than debond 1 (G2-BC1) (average difference: 152.81s, adjusted p-value=0.0002). Debond 3 (G2-Rx1) was also longer than debond 2 (G2-BC2), but this difference was not statistically significant (average difference=74.4 seconds, adjusted p-value=0.0732). All further analyses were performed by debond attempt due to the varying conditions of the attempt. *(Figure 10)*

Figure 10: Debonded Primary Tooth Showing Crown and Remaining Cement



The time to debond was significantly, positively correlated with inner surface area (r=0.59), inner volume (r=0.67), outer volume (r=0.73), and the cement volume (r=0.54). Although they were not statistically significant, it was also negatively correlated with the ratio of the outer to the inner surface area (r=-0.38), and the ratio of the volume (r=-0.27). This indicates that crowns that are larger relative to the abutment are faster to debond. A similar pattern was seen for the second debond, with significant positive correlations between time to debond and: total crown volume (r=0.57), inner surface area (r=0.80), outer surface area (r=0.71), inner (r=0.79) and outer (r=0.71) volume. Again, the debond time was negatively correlated with the ratio of the inner to outer surface area (r=-0.53) and volume (r=-0.50) but these were not statistically significant. The time for the third debond (G2-RX1), which utilized a different cement (RelyX), was not significantly correlated with any of the measures, but the strongest correlation was with the cement volume (r=0.38). Correlations are given in *Table 2*.

Table 2: Pairwise Correlations between Crown Metrics and Time to Debond

	Permanent Teeth			Primary Teeth	
	Debond 1	Debond 2	Debond 3	Debond 1	Debond 2
Crown Volume	0.433	0.573*	0.070	0.328	0.201
Inner surface area	0.586*	0.801*	0.059	0.225	0.181
Outer surface area	0.506**	0.711*	0.008	0.573**	0.408
Ratio surface area (outer:inner)	-0.376	-0.528**	-0.096	0.298	0.310
Inner volume	0.665*	0.792*	0.219	-0.085	0.188
Outer volume	0.727*	0.714*	0.251	0.381	0.441
Ratio volume (outer:inner)	-0.267	-0.500**	-0.091	0.505**	0.164
Cement volume	0.539**	0.123	0.377	0.623*	0.632*

*significantly different from 0, p-value<0.05

**marginally significantly different from 0, 0.05≤p-value≤0.10

Due to the high correlations among the crown metrics, they could not all be considered for the overall models for time to debond. The cement volume and the ratio of inner to outer surface area were selected as the most informative and utilized for the analysis. The pairwise correlation for these two variables was low (r=0.08, p-value=0.4966).

Cement volume was associated with a significant increase in the time to debond permanent crowns for the first debond settings. *(Figure 11)* For a 1mm^3 increase in the volume of the cement, the debond time required an additional 1.2 seconds (p-value=0.0224). There was marginal evidence of a significant decrease in first permanent molar debond time by an estimated 14.4 seconds for a 1-unit increase in the ratio (p-value=0.0654). Cement volume was not significantly associated with permanent molar debond time for the second (p-value-0.4536) or third (p-value-0.2485) debond attempts. There was marginal evidence of a significant decrease in second debond time for permanent molars by an estimated 16.26 seconds for a 1-unit increase in the ratio (p-value=0.0600. *(Figure 12)* Complete results are given in *Table 3.*

*Figure 11**:** Correlation of Cement volume to Debond time in Permanent Teeth*

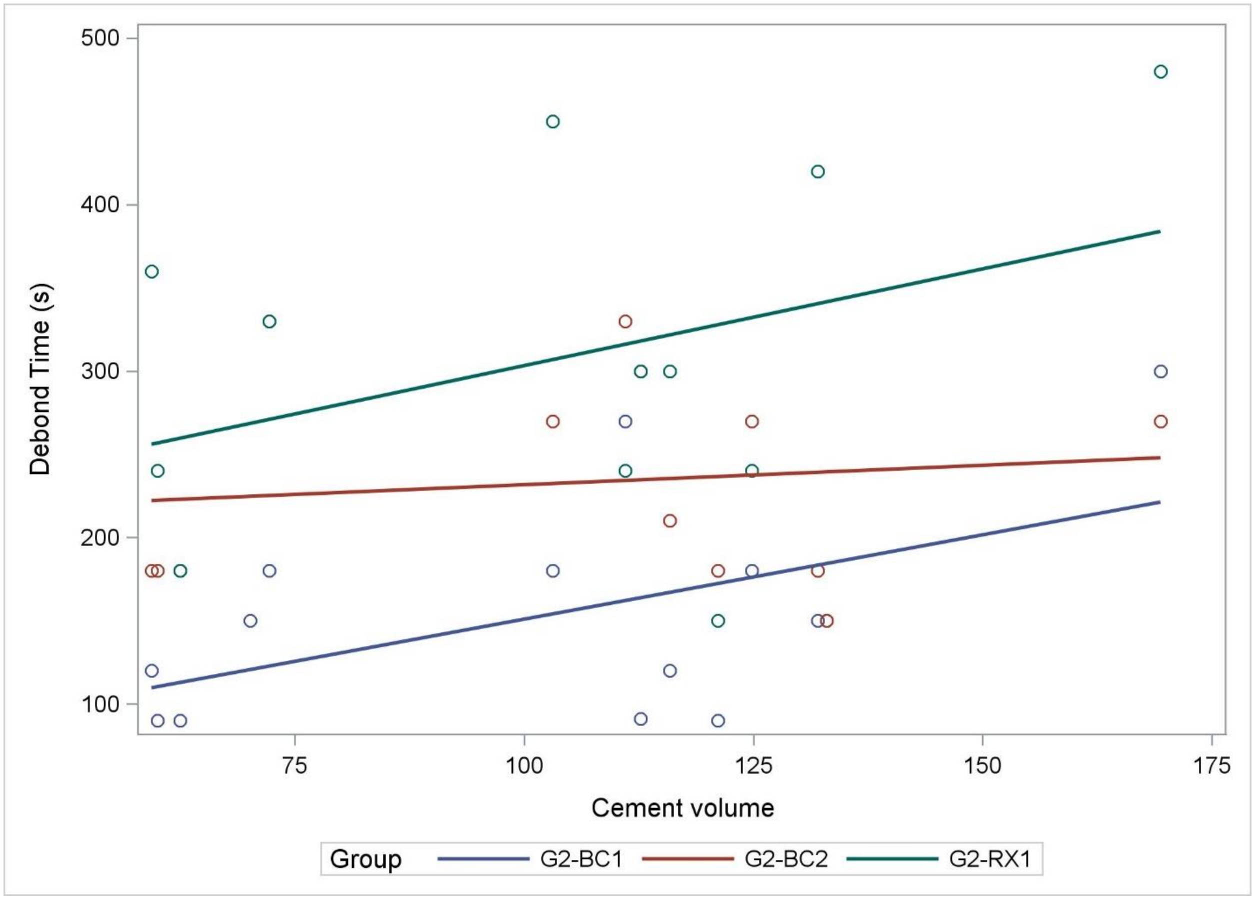


*Figure 12**:** Correlation of Outer to Inner Surface Area Ratio to Debond Time for Permanent Teeth*

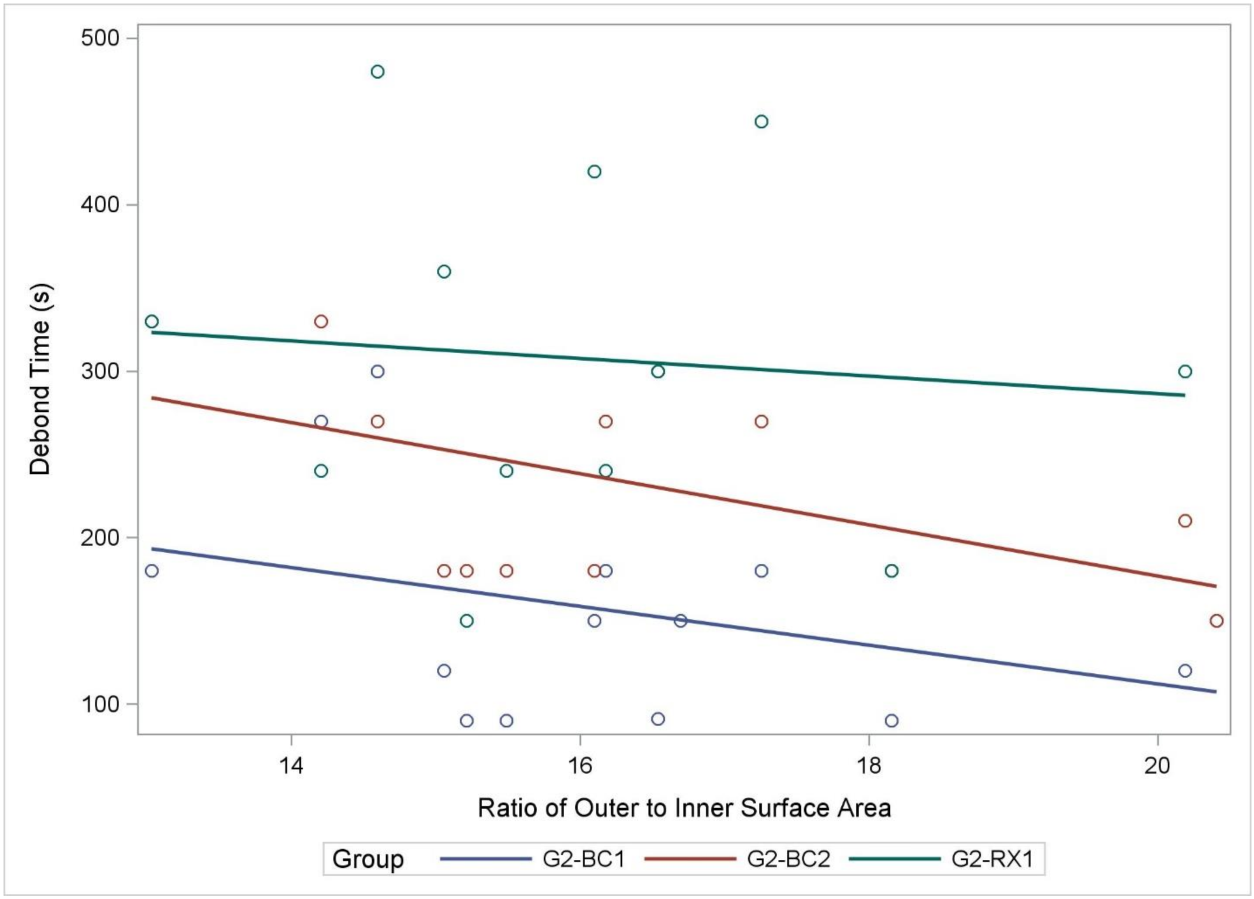
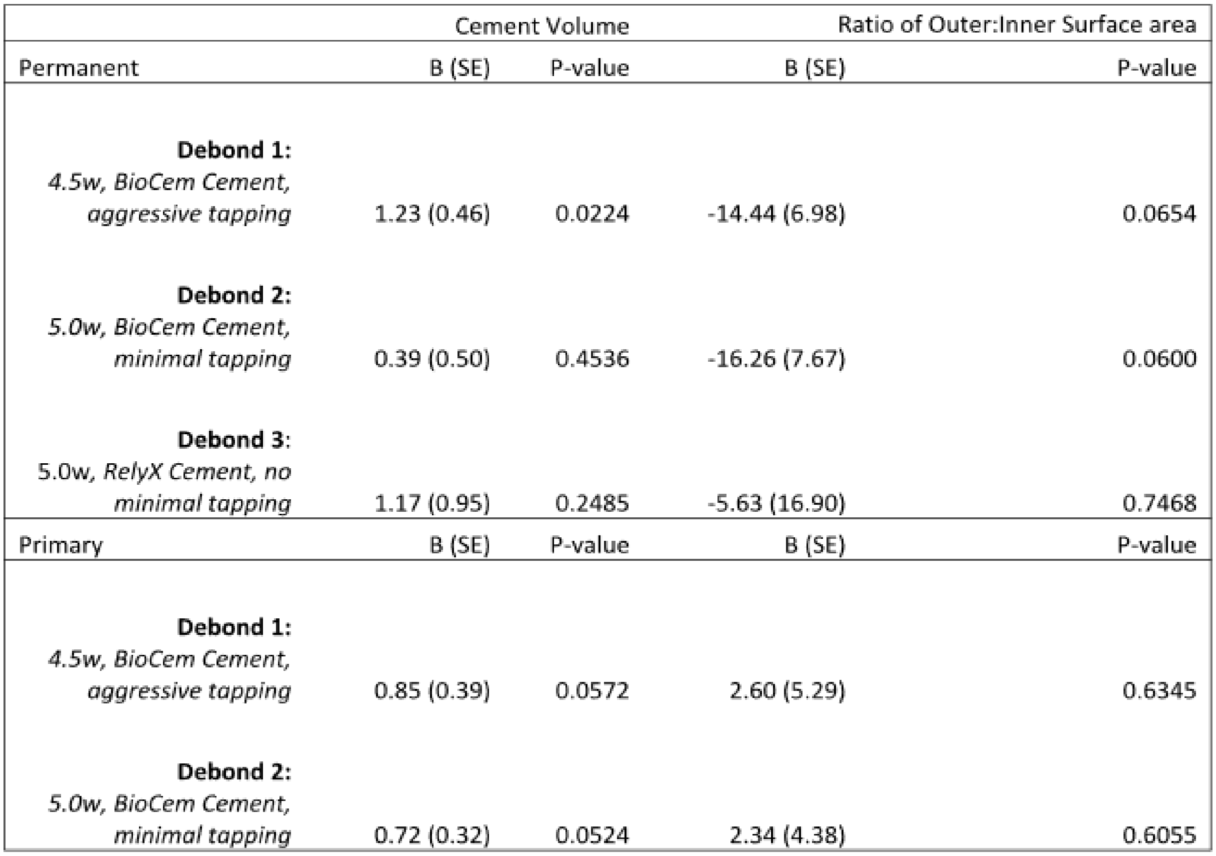


Table 3: Linear Regression Results for Relationship between Cement Volume, Ratio of Outer to Inner Surface area and Time to

Debond



	Cement Volume		Ratio of Outer:Inner Surface area	
Permanent	B (SE)	P-value	B (SE)	P-value
Debond 1: *4.5w, BioCem Cement, aggressive tapping*	1.23 (0.46)	0.0224	-14.44 (6.98)	0.0654
Debond 2: *5.0w, BioCem Cement, minimal tapping*	0.39 (0.50)	0.4536	-16.26 (7.67)	0.0600
Debond 3: 5.0w, *RelyX Cement, no minimal tapping*	1.17 (0.95)	0.2485	-5.63 (16.90)	0.7468
Primary	B (SE)	P-value	B (SE)	P-value
Debond 1: *4.5w, BioCem Cement, aggressive tapping*	0.85 (0.39)	0.0572	2.60 (5.29)	0.6345
Debond 2: *5.0w, BioCem Cement, minimal tapping*	0.72 (0.32)	0.0524	2.34 (4.38)	0.6055

Since the average debond time was the same for both debond attempts with deciduous teeth, it was not statistically significant (p-value=1.00). Time to debond for the deciduous teeth was only significantly correlated with the cement volume (r=0.62, 0.63 for the two debond attempts respectively). *(Figure 13)* The ratio of the outer to inner surface area was not significantly associated with the debond time for the deciduous crowns for either the first (p-value=0.6345) or the second (p-value=0.6055) debond attempts. *(Figure 14)* The cement volume was marginally significantly associated with the debond time for deciduous crowns at both debond attempts. For the first attempt, a 1-mm^3 increase in cement volume had an estimated .85 second increase in the time to debond (p-value=0.0572). For the second attempt, a 1mm^3 increase in cement volume was associated with a .72 second increase in the time to debond. Complete results are given in *Figure 13*.

Figure 13: Correlation of Cement volume to Debond time in Primary Teeth

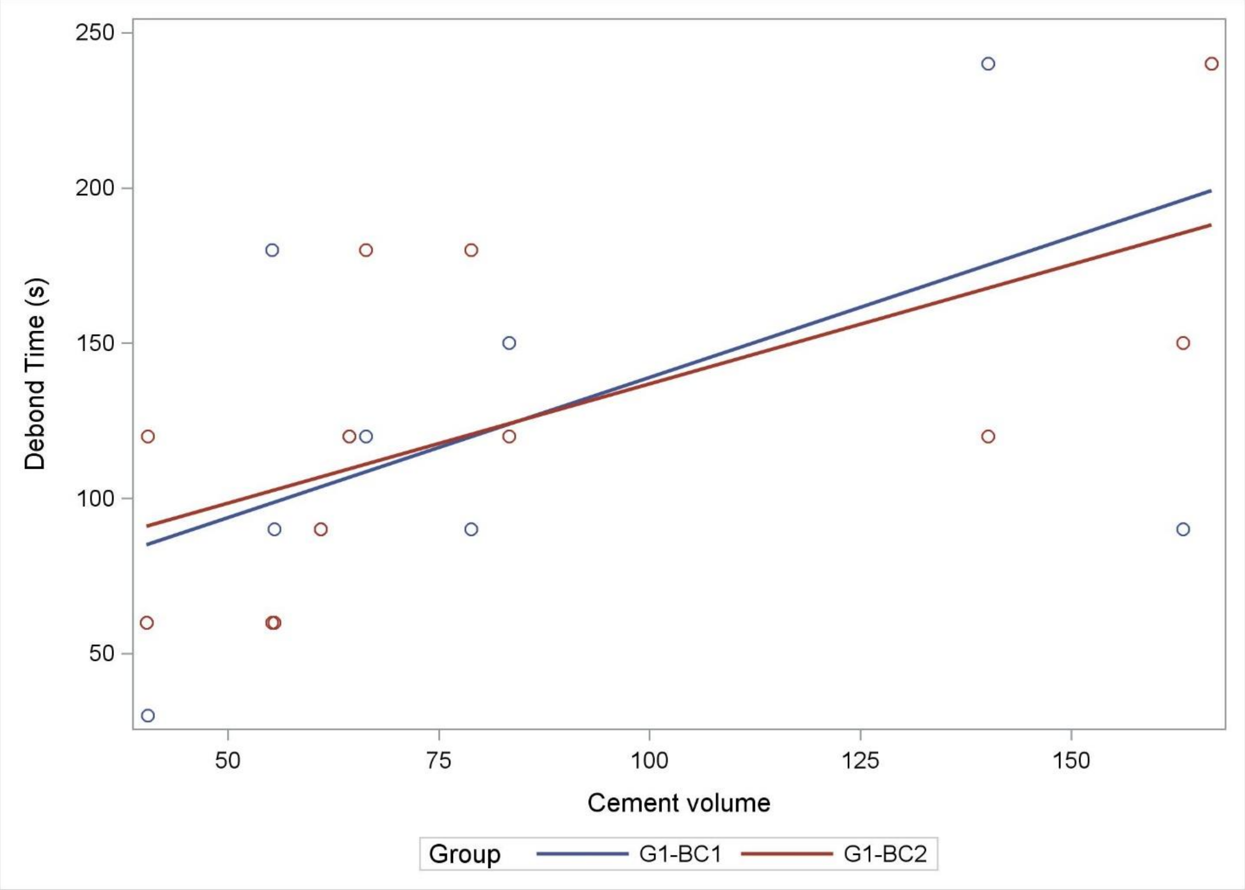
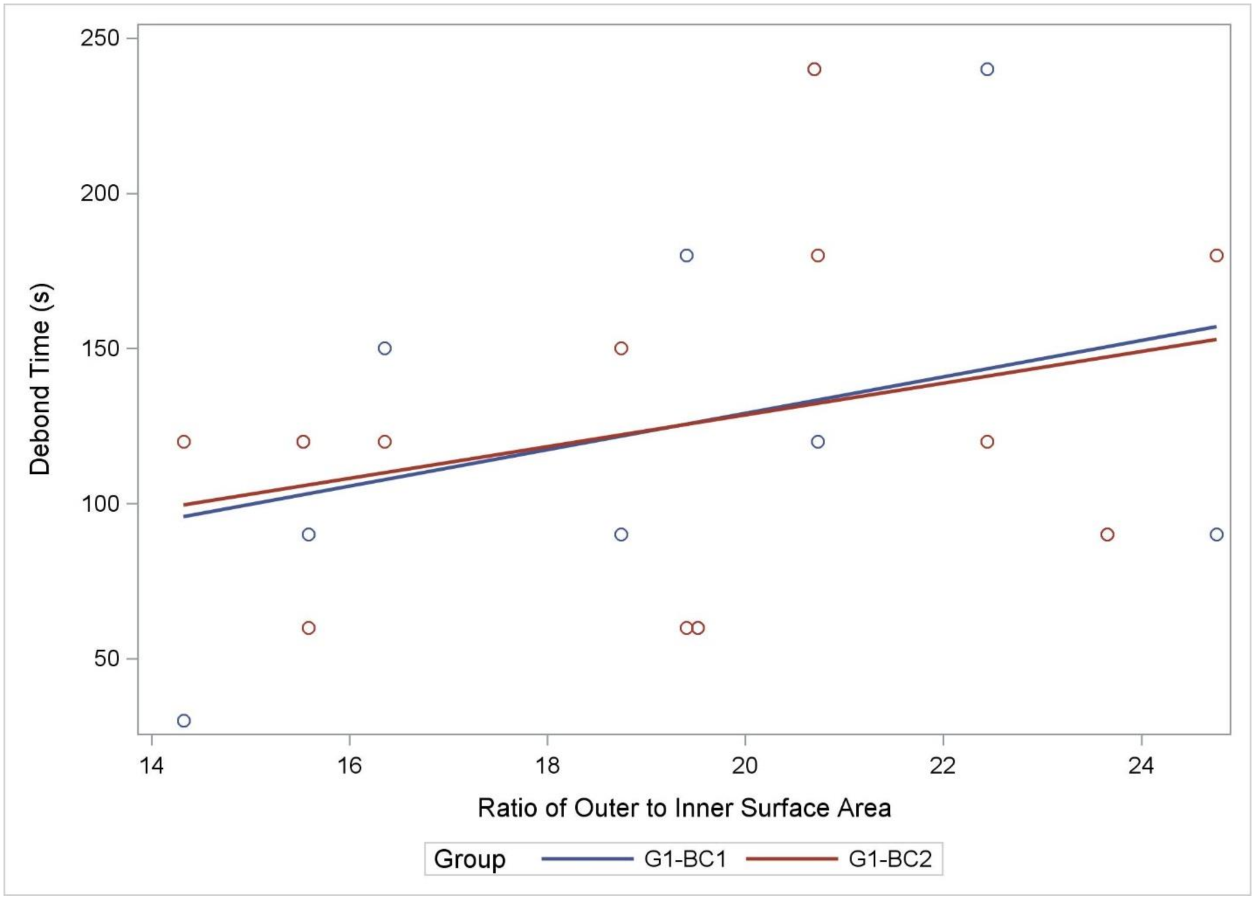


Figure 14: Correlation of Outer to Inner Surface Area Ratio to Debond Time for Primary Teeth



Temperature

The mean temperature changes were 2.48 (SD=1.43) ℃ for permanent teeth, 3.14(SD=1.88) ℃ for deciduous teeth. Although the deciduous teeth had greater temperature change, the difference was not statistically significant (p=0.1219). *(Table 4)*

With higher laser setting *(Table 5)* for the second group (G2-B2) of permanent crowns (increase from 4.5W to 5 W), the maximum temperature observed increases by 3.8 degrees compared to the first group (G2-B1) (p-value<0.0001). The average temperature change was not significantly different between first (G2-B1) and second (G2-B2) group (average difference: 0.12; p-value=0.7590).

Table 4: Summary of Crown Temperature during Debonding

	Maximum Temperature	**SD**	**Range**	**Average Delta**	**SD**	**Range**
Permanent						
Debond 1 *(4.5w, BioCem Cement, aggressive tapping)*	22.9	0.93	21.9-25.6	2.4	0.98	0.1-4.5
Debond 2 *(5.0w, BioCem Cement, minimal tapping)*	26.8	1.03	24.5-28.6	2.1	1.19	0.4-4.2
Debond 3 (*5.0w, RelyX Cement, no minimal tapping*	26.6	1.16	25.5-29.9	3.0	1.98	1.6-8.9
Primary						
Debond 1 *(4.5w, BioCem Cement, aggressive tapping)*	26.1	2.82	22.1-30.7	4.0	2.17	1.0-8.1
Debond 2 *(5.0w, BioCem Cement, minimal tapping)*	26.7	1.49	24.4-29.9	2.4	1.17	1.1-4.9

Table 5: Settings of Biolase Waterlase iPlus

Electrical

- Operating Voltage: 100 VAC ± 10% / 230 VAC ± 10%
- Frequency: 50 / 60 Hz
- Current rating: 5A / 8A
- Main Control: Circuit breaker

Air and Water Output

- Water type: Distilled or De-Ionized Only
- External air source: 80 – 120 psi. (5.5 – 8.2 bar)
- Water: 0 – 100%
- Air: 0 – 100%
- Interaction zone: 0.5 – 5.0 mm from Handpiece Tip to target

Optical

- Laser classification: 4
- Medium: Er,Cr:YSGG (Erbium, Chromium; Yttrium, Scandium, Gallium, Garnet)
- Wavelength: 2.78 μm (2780nm)
- Frequency: 5 – 100 Hz
- Average Power: 0.1 – 10.0 W
- Power accuracy: ± 20%
- Pulse energy: 0 – 600 mJ
- Pulse duration for "H" mode: 60 μs
- Pulse duration for "S" mode: 700 μs
- Handpiece head angles: 70° contra-angle
- Gold HP Tip diameter range: 200 – 1200 μm
- Turbo Tip focal diameter range: 500 – 1100 μm
- Output divergence: ≥ 8° per side
- Mode: Multimode
- Aiming Beam: 635nm (red) laser, 1mW max (safety classification 1)
- Water Level Sensor Beam: 635nm laser, 1mW max (safety classification 1)
- Nominal Ocular Hazard Distance (NOHD): 5 cm
- Maximum Permissible Exposure (MPE): 3.5 x 105 W/m2

SEM Examination

The SEM examination showed no visual damage to the crown caused by treatment with Er,Cr:YSGG laser. Inner surface of the crowns was covered by a thick cement layer, both the primary and permanent teeth, regardless of first, second or third laser irradiation. *(Figure 15)* Similarly, we observed no visual damage on the teeth surfaces. We noticed no major differences on the roughness of the tooth surfaces after the first, second and third laser debonding on the both, primary and permanent teeth. No cracks or fractures with micro and macrostructure was observed. *(Figure 16)*

Figure 15: Scanning Electron Microscope Image of the Surface of the Zirconia Crown Following Irradiation with Er,Cr:YSGG Laser

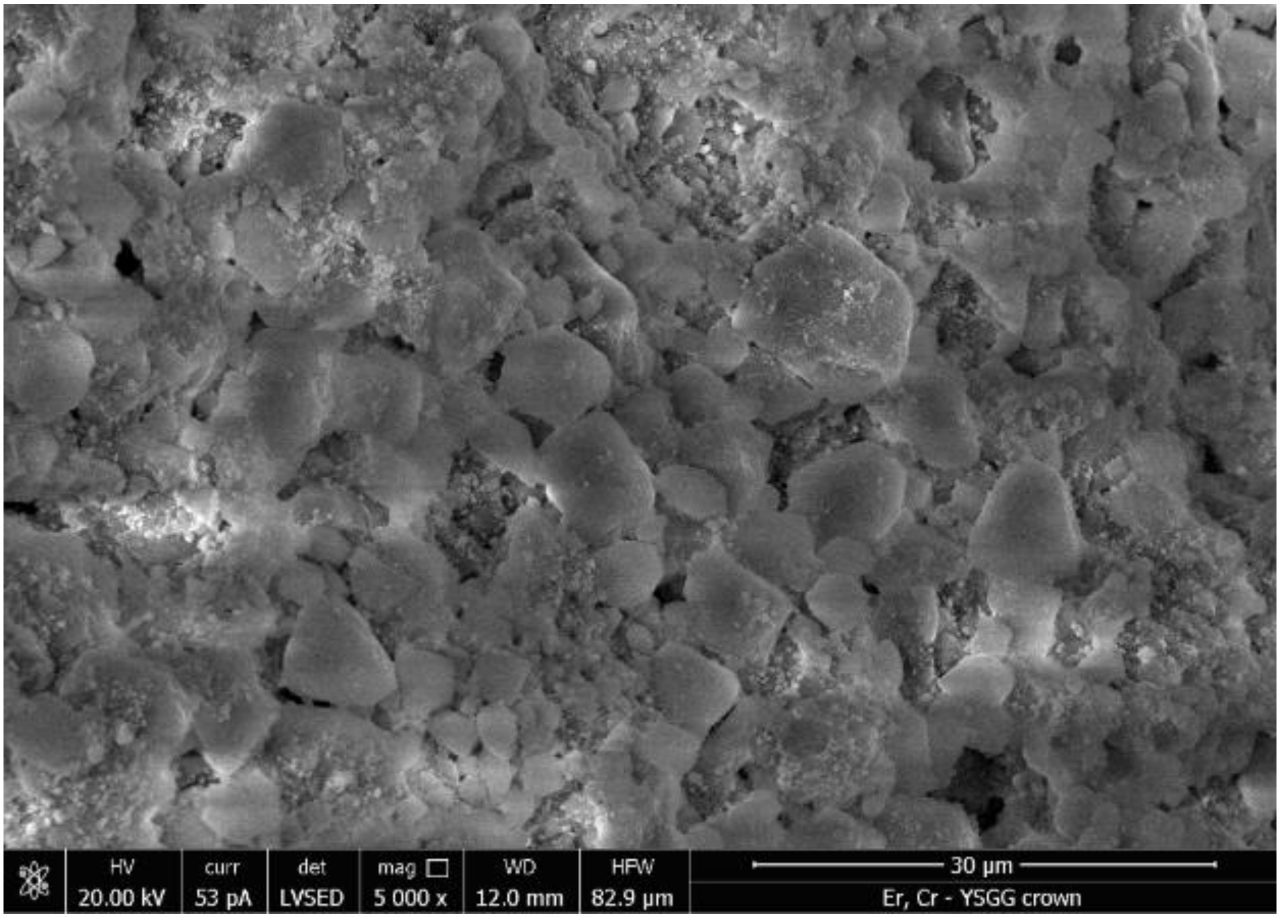
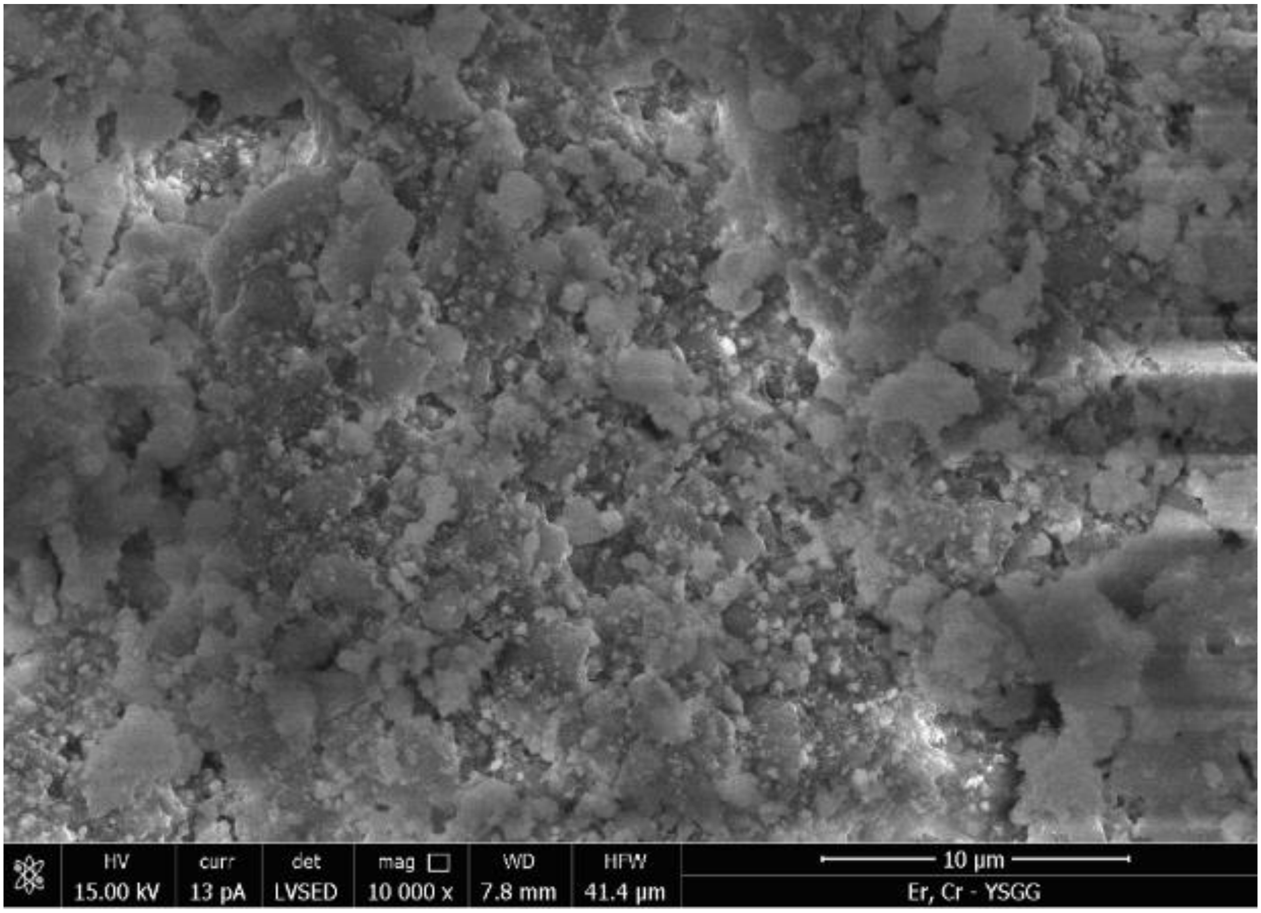


Figure 16: Scanning Electron Microscope Image of the Surface of the Tooth Following Irradiation with Er,Cr:YSGG Laser



Discussion

Prefabricated zirconia crown use is increasing in pediatric dentistry, and with their improved esthetics, have proven to be a viable alternative to stainless steel crowns. Laser assisted crown removal offers a good alternative to rotary instrumentation. Laser assisted crown removal is aimed at minimizing patient discomfort without damaging additional tooth structure or pulpal tissue

For this study, Er,Cr:YSGG (Biolase® Waterlase iPlus) laser was used. This laser is an all-tissue laser with ability to treat hard tissue and soft tissue and was chosen because of its availability in dental practices due to its ability to treat multiple tissues. Waterlase iPlus has more clearances and indications than any other dental laser. With its intuitive graphic user interface, it can be utilized to treat and manage the following conditions: periodontitis and peri-implantitis, cavity preparations, subgingival class 5 cavity preparations, gingival recontouring, frenectomy, root canal therapy, pulpotomy, troughing, implant recovery, posterior osseous crown lengthening, repair perio and biopsies. Additionally, the laser comes pre-programmed with over 56 pre-set procedures and adjustable settings as needed. It comes with a small diameter, titanium fiber cable and illuminated contra-angle handpieces to help eliminate fatigue and allow for increased access. As previously mentioned, lasers are incorporated to simplify dentistry, minimize chair time, and increase case acceptance with a patient-preferred, minimally invasive treatment option.[33]

Prefabricated zirconia crowns rely on a passive-fit for cementation and unlike the SSCs do not allow for mechanical retention. Following the principles of fixed prosthodontics, one may assume that a better fitting crown may take longer to debond. Although not statistically significant, the first (G2-BC1) and second (G2-BC2) permanent debond groups showed that larger crowns relative to the abutment are faster to debond, reinforcing the importance of proper crown size on retention. This trend was not found on the third (G2-RX1) debond group that utilized a different cement (RelyX). Although inconclusive, this difference could be contributed to the properties of the cements, including but not limited to greater or lesser water or monomer content that correlates with wavelength ablation. This could also be contributed to more retentive features on permanent teeth and better fitting crowns overall. More research is needed to analyze the specific type of cement as it relates to debond times using the Er,Cr: YSGG laser.

Furthermore, greater cement being associated with a longer time to debond could be contributed to needing more laser energy to ablate the water and monomer components of the cement which somewhat coincides with the above data pertaining to “crown-fit”. Given that the crown and cement volumes were not standardized; conclusions cannot be made on why this may be. More research is needed on this topic to further explore the differences.

The force of digital palpation can affect the debonding time. When stronger tapping forces are applied, the crown can be removed following shorter irradiation time, as was evident from results in the first set of groups. Tapping forces on an extracted tooth can easily exceed comfort levels for an in-vivo case, especially in a pediatric setting. For sensitive patients who cannot tolerate as much pressure or with a concern of causing iatrogenic tooth fracture by delivering excessive tapping force, the irradiation time can be extended by 1-2 minutes. Following the increased irradiation time, a very gentle tapping force may be required for crown removal.

Although not previously mentioned, another consideration that was clinically evaluated during the study was the potential risk of ceramic fracture with laser irradiation. Morford et al. study analyzed esthetic veneers and noted an average of 36% Empress Esthetic veneers fractured during the debonding process. This was likely because the veneers were kept in saline solution for 5 days before the procedure, resulting in water absorption of porous porcelain and rapid expansion of the water during laser ablation. Although no statistical analysis was done, the zirconia crowns in our study did not exhibit any clinical signs of fracture after laser removal. This was likely due to the high flexural strength and less porosity of zirconia.[40,41]

Though not statistically analyzed, additional irradiation time demonstrated less cement on the abutment tooth clinically and more cement being retained in the crown, an interesting finding Also, when greater force was exerted for crown removal in the first debonds for both primary (G1-BC1) and permanent teeth (G2-BC1) more cement was retained on the abutment tooth. This may be contributed to higher power laser settings in the second groups, longer irradiation time or variations in removal force. Lastly, though not yet published, Yepo Hou et al. state that an Er:YAG laser can etch teeth, leading to increased shear bond strength and decreased microleakage of self-glazed ceramics.[42] This aforementioned data could contribute to longer crown removal in subsequent debonds. More research is needed to make definitive conclusions on these findings but initial results show higher power irradiation and longer irradiation makes for cleaner crown removal.

Temperature changes were measured in the pulpal chamber. For all experimental groups temperatures were within the tolerable range throughout the irradiation with laser; however, the differences among the groups can be attributed to proximity of the pulp to surfaces targeted with irradiation and power setting of the laser. Primary teeth have larger pulps and less dentin, and thus heat generated during irradiation may more easily affect the pulp.[43] Similar trends were observed in the smaller molars. Higher power irradiation did not improve the debonding efficiency at the expense of higher recorded temperature changes. Therefore, it would be recommended to use lower settings, especially on teeth with larger pulps demonstrating a decreased dentinal barrier between the cement and pulp. Additionally, as previously discussed, longer irradiation time does not lead to higher temperature increases and therefore an additional minute or two of irradiation may be preferable to aggressive tapping forces or higher power settings.[44]

Conclusion

Investigating the effect of the Er,Cr:YSGG laser on the debonding time of prefabricated zirconia crowns and dental pulp temperature, the present study showed that application of Er,Cr:YSGG was an efficient, fast and safe method for the removal for both permanent and primary molars. During laser irradiation, the mean temperature changes were 2.48 (SD=1.43) ℃ for permanent teeth, and 3.14 (SD=1.88) ℃ for primary teeth, well within physiologic parameters from previous studies, and there was no significant difference among the groups under tested laser parameters. Clinically, this method of crown removal could be utilized when a patient is needing a prefabricated zirconia crown removed to be replaced for a permanent restoration. Additionally, when cementing anterior crowns, and they are not aligned on final cementation, this method could possibly be used to provide a quick removal and rebond. Future research is needed to investigate the effect on pulpal temperature in anterior teeth but Er,Cr:YSGG lasers continue to prove their effectiveness.

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