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Effect of Erbium, Chromium-doped: Yttrium, Scandium, Gallium and Garnet Laser Tooth Preparation on Gap Formation of Universal Adhesive Bonded to Enamel and Dentin: A Micro-CT and SEM Study

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Abstract

Introduction: The presence of gaps at the bonding interface of resin composite restorations is known to have an impact on restoration longevity. This study aimed to evaluate the effect of erbium, chromium-doped yttrium, scandium, gallium, and garnet (Er, Cr:YSGG) laser irradiation on gap formation at the tooth–resin interface and to compare the reliability of micro-computed tomography (µCT) and scanning electron microscopy (SEM) scans for gap formation assessment.

Methods: Thirty standardized non-retentive class V cavities were prepared on sound human premolars using either an Er,Cr:YSGG laser or a round carbide bur (n = 15 for each). A universal adhesive and A nano-filled resin composite were applied in accordance with the manufacturer's recommendations. After water storage for 24 hours at 37°C, the teeth were subjected to thermocycling. Gap formation assessments were performed by µCT (Skyscan 1173 µCT, Brucker, Belgium) and SEM (JEOL JSM-6610LV, Japan), and SPSS version 24.0 (IBM Inc., Chicago, USA) was used to analyze the data at *P* value < 0.05. Descriptive statistics were used to describe the gap formation percentages. To compare the impact of both preparation and assessment methods, a non-parametric Mann–Whitney U test was used.

Results: In enamel, similar gap formation values were detected for the two preparation methods (bur and laser). However, the laser-prepared group showed higher gap formation values in dentin. Additionally, higher gap formation values were reported for both preparation methods when µCT was used for assessment.

Conclusion: Cavity preparation using a Waterlase laser led to higher gap formation percentages at the dentin–resin interface. In addition, SEM assessment is more reliable for assessing the tooth–resin interface.

Keywords: Erbium; Lasers; Dental cavity preparation; Scanning electron microscopy; X-ray microtomography

Introduction

Laser technology was used in various dental applications such as caries prevention, cavity preparation and disinfection, and management of hypersensitive teeth.[1-4] The most commonly used laser is the erbium laser, with two distinct types (erbium, chromium-doped yttrium, scandium, gallium, and garnet [Er,Cr:YSGG] and erbium-doped yttrium, aluminum, and garnet [Er: YAG] lasers). Compared to other dental laser types such as carbon dioxide (CO_2) and neodymium-doped yttrium aluminum garnet (Nd: YAG) lasers, erbium lasers have a higher affinity for hydroxyapatite and water absorption. Erbium lasers are, therefore, employed for both hard and soft tissue operations.[5] They are considered the most promising dental lasers that operate at a wavelength of 2.94 µm (2940 nm), which matches the absorption peaks of water and hydroxyapatite. When safe and effective parameters are applied, cavity preparation can be performed with a minimal negative effect on the pulp.[6] This approach produces less noise, pressure, and vibration than conventional methods of cavity preparation.[7]

Losses in the interfacial tooth–restoration seal (gaps) affect the success of dental restorations. The presence of gaps at the bonding interface of resin composite restorations and internal voids within the body of restorations affects the mechanical properties and longevity of the restoration.[8] Furthermore, bacterial microleakage, secondary caries, and hypersensitivity in restored vital teeth may arise as a result of such gaps.[9,10] In addition, other factors such as cavity configuration

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and preparation, type of adhesive system and restorative material composition, insertion technique, curing technique, or interactions among all these factors can result in gap formation.[11-13]

Scanning electron microscopy (SEM) was reported by Tosco et al to be a reliable modality for quantitatively assessing the margins and adaptation of dental restorations.[12] However, SEM is a destructive method that requires sectioning of the samples. Another limitation is that the accuracy of the measurement depends on the site of the section and the viewing angle.[14]

Micro-computed tomography (µCT) is a three-dimensional (3D) non-destructive method used to detect restoration adaptation and interfacial gaps. Both two-dimensional (2D) and 3D measurements over a range of a few micrometers for multiple locations and directions can be achieved with µCT technology.[12] In 2017, Matsumoto et al compared the effectiveness of the conventional method (transmission electron microscopy, TEM) and non-destructive µCT to detect gaps around the post and root dentin. The authors reported that µCT can reveal gaps and bubbles in post-core spaces without destruction of the samples.[15] In agreement, in 2020, Sampaio et al concluded that µCT technology is a valid alternative to SEM for diagnosing external gap formation around resin composite restorations.[16] However, µCT is an expensive method that is generally limited to laboratory research.

Several studies have investigated the effect of the Er,Cr:YSGG laser on irradiated surfaces. However, the effect of this type of laser on gap creation at the tooth–resin interface is still unknown. The objectives of this study were (1) to evaluate the effect of Er, Cr: YSGG laser preparation on gap formation where a universal adhesive is applied to enamel and dentin surfaces compared with conventional bur-cut preparation and (2) to compare the validity of µCT to SEM scans for gap detection in resin composite restorations.

Materials and Methods

Teeth Selection and Preparation

Thirty sound human premolars extracted for orthodontic reasons were collected. Immediately after extraction, the teeth were rinsed under running water and stored in a dark glass containing distilled water and 0.05% thymol solution at room temperature for a maximum of one week. Then, the extracted teeth were cleaned and polished using a scaler and non-fluoridated pumice with a rubber cup and slow-speed contra-angle handpiece (W&H Dentalwerk Burmoos, Austria). The teeth were examined visually and under a SWIFT optical microscope (Tri County Pkwy, Schertz, TX, United States) at 20X magnification to ensure that they were free of caries, decalcification, cracks, abrasion facets, and damage from extraction. The experimental teeth were then stored in another dark glass container with distilled water and 0.05% thymol solution at room temperature until cavity preparation time (a maximum of one week).

Cavity Preparation

On the buccal surfaces of all teeth, thirty round non-retentive cervical class V (Cl V) cavities (4 mm in diameter and 2 mm deep) were prepared. The cavities were prepared randomly using either a round tungsten carbide bur as a control (Wave Dental, Worcester, MA, USA) or an Er,Cr:YSGG laser (Waterlase Millennium™, Biolase Technologies, Inc., San Clemente, CA, USA) (n = 15 for each) (Figure 1). External occlusal margins were applied over enamel (2 mm above the CEJ) while gingival margins were applied over dentin (2 mm below the CEJ). For cavity standardization, a round hole with a diameter of 4 mm was punched on a plastic strip and attached to the tooth using a piece of utility wax before cavity preparation. The cavity depth was measured by a periodontal probe (William's probe).

For the bur-cut group (Bur group), samples were prepared using round friction-grip tungsten carbide burs (No. 7) with a head diameter of 2.1 mm (Wave Dental, USA) mounted in a Bien Air high-speed handpiece (Black Pearl, TLC, Bienne, Switzerland) attached to a Planmeca dental unit (Oy, Helsinki, Finland) under an air–water spray coolant. After every five preparations, a new bur was used.

Cavities in the Er,Cr:YSGG laser group (W group) were prepared by a Waterlase Millennium™ laser, which emits photons at 2.78 µm, and an MZ6 sapphire Waterlase tip (600 µm in diameter and 9 mm long). At the beginning, the teeth were irradiated using laser parameters recommended by the manufacturer. However,

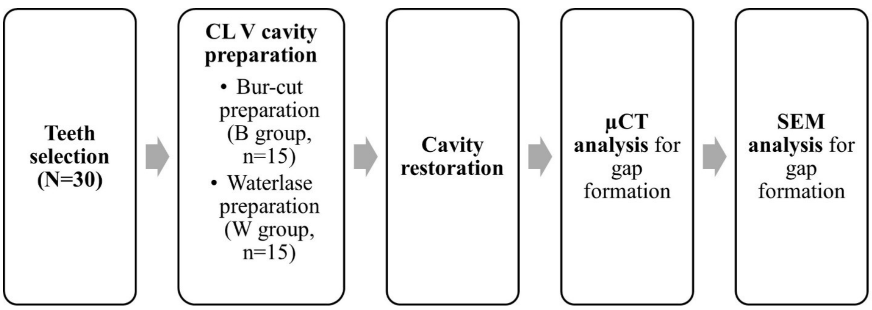

Figure 1: A Flowchart of the Experimental Groups.

laser parameters were modified for optimal enamel and dentin removal on extracted teeth based on the results from a pilot study. A focused beam of 8.00 W at 70% air pressure level and 90% water level and at a frequency of 20 Hz was used. At a separation of 1–2 mm, the laser tip was perpendicular to the tooth surface. The laser emitted pulses with a pulse duration of 60 µs, pulse energy of 600 mJ, a fluency (energy density) of 214.3 J/cm^2 per pulse, and an irradiance (power density) of 2857 W/cm^2. After cavity preparation, all prepared teeth were stored in the dark in a container filled with distilled water at 37°C for 24 hours.

Application of Adhesive and Resin Composite Material

All materials were utilized in accordance with the manufacturers' recommendations (Table 1). Universal dentin adhesive (Adper Single Bond Universal, 3M ESPE, St. Paul, MN, USA) was used with selective enamel etching. Enamel surfaces were acid-etched for 15 seconds using 37.5 % phosphoric acid. After that, the etched surfaces were washed for 20 seconds or until the etchant was completely removed and then dried gently by an air spray for 5 seconds. Next, adhesive was applied over the prepared surfaces for 15 seconds with a light scrubbing motion and light-cured for 20 seconds by a high-power light-emitting diode (LED) light-curing unit (Elipar™ S10 LED, 3M ESPE, St. Paul, MN, USA). The light intensity (1200 mW/cm^2) of the light-curing unit was verified by a radiometer (Ivoclar Vivadent, Schaan, Liechtenstein) for each session.

Following adhesive application, a nano resin composite (Filtek Supreme Ultra, body shade A2B) was placed in one increment (2 mm) and light-cured through a Mylar strip (0.05 mm thick) by an Elipar™ S10 LED for 40 seconds. The samples were stored in distilled water in Memmert Universal Oven (Memmert GmbH + Co.KG, Schwabach, Germany) set at 37°C for 24 hours to ensure complete polymerization of the materials. Then, all the samples were number-coded and subjected to artificial thermocycling aging for 5000 cycles by an SD Mechatronik thermocycler machine (SD Mechatronik, Feldkirchen-Westerham, Germany). During thermocycling aging, the samples were immersed in distilled water baths at 5°C and 55°C for 20 seconds each, with a 10 second transfer period between each water bath. All cavities were prepared and restored by the same operator.

µCT Analysis and Imaging

All prepared teeth (n = 30) were scanned by a Skyscan 1173 µCT (Brucker, Belgium). During µCT examination, the teeth were wrapped with wet gauze to ensure hydration. The images were converted to tomograms for gap measurement using Skyscan CT-analyzer TM (CT-An) software. The mean gap formation percentage (%) at the enamel and dentin surfaces was determined by the following equation: [(P/L) X100], where P is the interfacial gap length at the enamel (or dentin) and L is the total length of the prepared enamel (or dentin) wall.

SEM Analysis and Imaging

Sample Preparation for SEM Examination

After µCT scanning, the teeth were embedded in orthodontic acrylic resin and sectioned in the mesiodistal direction and parallel to the tooth long axis into three sections by a circular disc blade with a thickness of 0.2 mm (Isomet 1000 Linear Precision Saw, Buehler, Lake Buff, Illinois, USA). Sectioned pieces were mounted into 6 cm cylindrical molds with epoxy resin and then polished by a Leco GPX 300 at a speed of 75 rpm using ascending silicon carbide paper (400, 600, 1200, and 2000 grit) for approximately 1 minute per grit under water cooling. Next, ultrasonic cleaning was applied for 5 minutes to remove debris.

The samples were then soaked in 35% orthophosphoric acid for 15 seconds and cleansed with running water. Subsequently, the teeth were immersed in 5% sodium hypochlorite solution (NaOCl) for 30 minutes and then rinsed under running water. All samples were then dehydrated in ethanol under different concentrations (70%, 80%, and 96%) in ascending order for 1 hour each.

After air-drying for 5–10 seconds, the teeth were placed in the sample stage of a sputter coating machine (Quorum, Q150R ES, UK), and a thin film (10 nm) of gold was deposited for 1 minute. All samples were loaded into a JEOL JSM-6610LV SEM (JEOL, Tokyo, Japan) for image processing and analysis. Four magnifications were used for sample analysis: 22X, 45X, 140X, and 400X.

The mean gap formation percentage (%) was calculated along the resin–tooth interface on the enamel and dentin surfaces by the following equation: [(P/L) X100], where P

Table 1. List of Materials Used in This Study

Type	Name (LOT)	Company	Composition
Nano resin composite	Filtek Supreme Ultra, shade A2B (N958713)	3M-ESPE, St. Paul, Min	Bis-GMA, Bis-EMA. UDMA, PEGDMA, TEGDMA, non-agglomerated/non-aggregated 20 nm Silica, and 4-11 nm zirconia fillers, and aggregate zirconia/silica cluster filler (Filler size: 0.6 to 10 µm, filler load: 55.6% by volume; 72.5wt.%)
Universal dental adhesive	3M™ Single Bond Universal Adhesive (00924B)	3M-ESPE, St. Paul, Min	Methacryloyloxydecyl Phosphate (MDP) monomer, Dimethacrylate resins, HEMA, Vitrebond copolymer, filler, Ethanol, water, initiators, and Silane.
Acid etchant	Gel Etchant (7361843)	Kerr, Orange, CA, USA	37.5% phosphoric acid solution

is the interfacial gap length at the enamel (or dentin) and L is the total length of the prepared enamel (or dentin) wall. The sample preparation procedures for µCT and SEM analysis were performed by a single operator who was not aware of the coding system.

Statistical Analysis

Statistical analysis was performed using SPSS 24.0 version statistical software (IBM, Inc., Chicago, USA). The gap formation percentage was described using descriptive statistics (mean and standard deviation). To assess the impact of various preparation methods [Er,Cr:YSGG laser (W group) and conventional bur-cut (B group)] on gap formation at both the enamel and dentin surfaces, a non-parametric Mann–Whitney U-test was used due to the skewed distribution of the values. This test was also used to compare the validity of SEM and µCT assessment methods for gap formation analysis in the enamel and dentin surfaces of the B and W groups. The results were presumed to be statistically significant if the p-value was less than 0.05.

Results

Effect of the Tooth Preparation Method (Er,Cr:YSGG Laser vs. Bur) on Gap Formation at Enamel and Dentin Surfaces

The gap formation (%) means and standard deviations (Sd.) for enamel and dentin surfaces prepared by either a bur (B group) or an Er,Cr:YSGG laser (W group), as examined by µCT, are given in Table 2. There was no statistically significant difference between the two preparation methods for the enamel ($P=0.652$) or dentin ($P=0.252$) surfaces when µCT was used to assess the samples. Similarly, there was no statistically significant difference between the two preparation methods at the enamel surface ($P=0.148$) when SEM was used to examine the samples, as shown in Table 3. However, there was a statistically significant difference between the two preparation methods for dentin surfaces assessed by SEM ($P=0.001$). A significantly higher gap formation (%) mean was found for dentin surfaces in the W group than in the B group when assessed by SEM.

Comparing µCT and SEM Assessments

Assessing the reliability of the two assessment methods used in this study, we found that there was no statistically significant difference ($P=0.067$) between the gap formation (%) means for the enamel surfaces in the W group analyzed by µCT or SEM. However, there was a statistically significant difference ($P<0.0001$) in the gap formation (%) mean for enamel surfaces of the B group assessed by µCT or SEM. Higher values were detected when B group samples were analyzed by µCT compared with SEM (Table 4).

Similarly, for the dentin surfaces, there was no statistically significant difference in the gap formation (%) means of the W group when assessed by µCT or SEM ($P=0.056$). However, significantly higher gap formation percentages were found when dentin surfaces of the B group were assessed by µCT compared with SEM ($P<0.0001$; Table 5).

Figures 2-5 show representative images of SEM and µCT analysis for the B and W groups. A smoother cavity floor can easily be observed for the bur-prepared group. The enamel in the W group shows microcracks and irregular surfaces. More detailed images of the tooth–resin interfaces were obtained by SEM compared with µCT (adhesive layer and hybrid layer). When the same section of a sample was observed by µCT, larger gaps and more gaps were detected compared with SEM observation.

Table 2. Comparison of Gap Formation Mean Percentages at Enamel and Dentin Surfaces Prepared by Bur or Waterlase and Analyzed Using µCT

Groups		Mean (SD) of Gap Formation (%)	Mean Rank	*P* Value
Enamel	B group	42.66 (25.76)	15.70	0.652
	W group	35.25 (25.50)	14.25	
Dentin	B group	14.10 (12.50)	13.20	0.252
	W group	17.81 (8.35)	16.93	

Table 3. Comparison of Gap Formation Mean Percentages at Enamel and Dentin Surfaces Prepared by bur of Waterlase and Examined Using SEM

Groups		Mean (SD) of Gap Formation (%)	Mean Rank	*P* Value
Enamel	B group	1.25 (1.57)	13.13	0.148
	W group	7.65 (13.48)	17.87	
Dentin	B group	1.86 (1.84)	10.53	0.001*
	W group	9.77 (12.87)	20.47	

*Describes a value with a statistically significant difference.

Table 4. Comparison of Gap Formation Mean Percentages at Enamel Surfaces Prepared by Different Preparation Methods and Examined Under SEM and µCT

Groups		Mean (SD) of Interfacial Gap (%)	Mean Rank	*P* Value
B group	SEM	1.25(1.57)	8.90	<0.0001*
	µCT	42.66(25.76)	22.10	
W group	SEM	7.65 (13.84)	12.53	0.067
	µCT	32.90 (26.20)	18.47	

*Describes a value with a statistically significant difference.

Table 5. Comparison of Gap Formation Mean Percentages at Dentin Surfaces Prepared by Different Preparation Methods and Examined Under SEM and µCT

Groups		Mean (SD) of Interfacial Gap (%)	Mean Rank	*P* Value
B group	SEM	1.86 (1.84)	9.80	<0.0001*
	µCT	14.10 (12.50)	21.20	
W group	SEM	9.77 (12.86)	12.49	0.056
	µCT	16.62 (9.27)	18.60	

*Describes a value with a statistically significant difference.

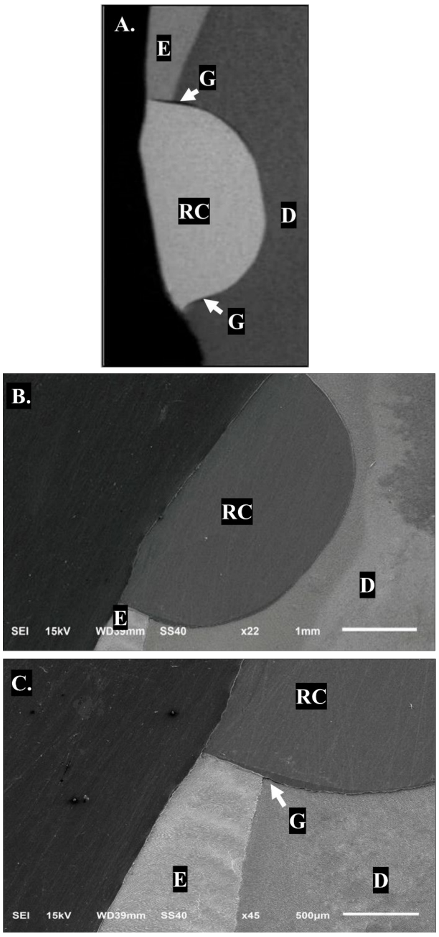

Figure 2. Representative Images of a Sample in Bur Group; (A) using µCT, (B) Under SEM with × 22 magnification, and (C) Under SEM with × 45 magnification. G: gaps, E: enamel, D: dentin, RC: resin composite, AD: adhesive layer, and H: hybrid layer.

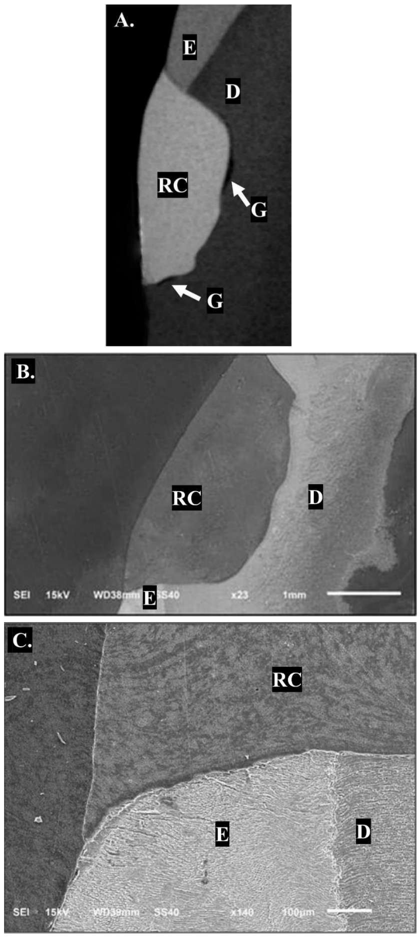

Figure 4. Representative Images of a Sample in Waterlase Group; (A) using µCT, (B) under SEM with × 23 magnification, and (C) under SEM with × 45 magnification.

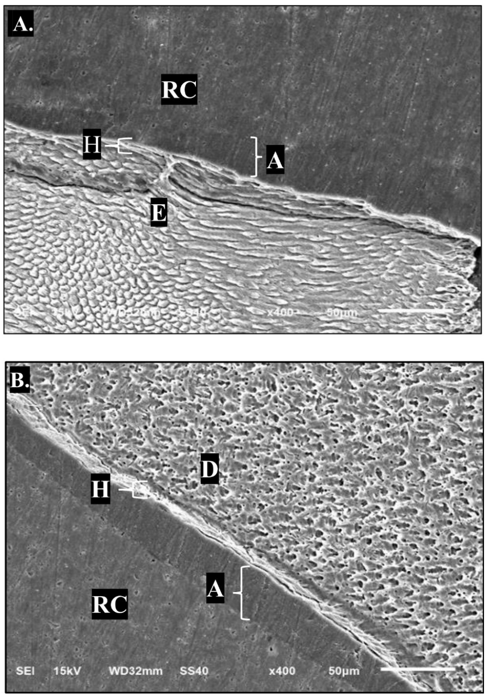

Figure 3. SEM Respective Images of the Same Sample in Bur Group Shown in Figure 2 With a Magnification of × 400 Show Gaps.

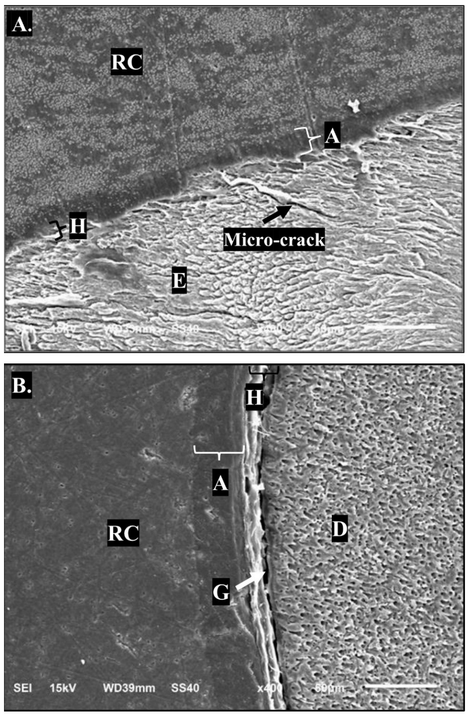

Figure 5. SEM Respective Images of the Same Sample in Waterlase Group Shown in Figure 4 With a Magnification of × 400 Show Gaps.

Discussion

In the literature, it has been concluded that erbium laser-irradiated enamel shows morphological and chemical changes resulting from micro-explosions during laser ablation.[17,18] Zones of melting, crystallization, and microcracks have been reported in previous studies. However, these alternations of the irradiated enamel surface should be minimal if adequate water cooling is used.[19,20]

Dental lasers interact with water and hydroxyapatite, which both play a major role in bonding interactions with hard dental tissues.[21] Increasing the temperature during Er,Cr:YSGG laser irradiation may affect the quantity of carbonate and hydroxyl groups in enamel. In addition, due to the evaporation of organic content in the enamel during irradiation, higher quantities of calcium (Ca) and phosphate (P) have been reported in earlier studies.[22] This change may affect the reaction between Methacryloyloxydecyl phosphate containing adhesives and the irradiated enamel because these adhesives can partially demineralize and chemically bond to Ca and P in hard dental tissues.[23] However, in this study, there was no significant effect of Er,Cr:YSGG laser irradiation on gap formation (%) at the enamel–resin interface. This finding could be due to the selected laser parameters and the use of copious water cooling. Sasaki et al reported a heterogeneous effect of erbium laser irradiation on enamel surfaces with non-lased enamel areas.[24] In this study, a selective enamel etching technique was used on both B and W groups, which may have caused the similar gap formation (%) means observed for the B and W groups.

The findings of this study revealed that the Er, Cr:YSGG laser and carbide bur methods for cavity preparation resulted in similar percentages of gap formation between universal adhesive (Adper Single Bond Universal) and enamel surfaces when observed by SEM and μCT. Irradiated enamel showed irregular surfaces in contrast to the enamel prepared using a bur, which showed smooth surfaces. This finding agrees with earlier studies that reported an irregular smear-free layer on irradiated surfaces.[19,25]

For the dentin–resin interface, the current study showed higher gap formation (%) in laser-irradiated dentin than in dentin prepared using a bur when examined by SEM. This finding can be attributed to several factors. Initially, laser irradiation causes the vaporization of water and other hydrated organic content within the target tissue, which leads to internal pressure elevation and finally explosive destruction of the inorganic substances, as mentioned earlier. Since intertubular dentin has a higher water and lower mineral composition than peritubular dentin, it is preferentially more ablated, leaving the dentin surface with a cuff-like appearance.[26] Previous studies have reported that erbium laser-irradiated dentin shows typical micromorphological features. These characteristics include rough irregular smear-free layer surfaces with protruding open peritubular dentin displaying microcracks and fissures.[26,27] In addition, some authors have reported melting and solidification of Er,Cr:YSGG laser irradiated dentin.[28,29] These morphological alternations might negatively affect resin hybridization.[30]

During dentin laser irradiation, heat is generated, resulting in thermal denaturation of the collagen, breaking of the hydrogen bonds, and three-polypeptide chains in a triple helical molecular structure, which results in an irreversible transformation and shrinkage of the collagen fiber network.[31] To minimize the effect of erbium laser irradiation on dentin, proper laser parameters should be selected. Shorter pulse duration and lower fluency minimize the amount of energy transferred into heat, thus reducing thermomechanical damage to the dentin microstructure. These factors also result in more efficient ablation performance with less thermal damage to the irradiated tissue.[31,32] Trevelin et al reported that the thickness of the altered dentin layer increases with increasing pulse duration.[31]

A higher gap formation (%) mean observed for the W group could be due to an increase in acid resistance of Er,Cr:YSGG laser irradiated dentin, as concluded in earlier studies.[17,18] This alternation in the acid resistance property is expected to negatively affect resin infiltration into the irradiated dentin.[33] The adhesive used in the current study has an ultra-mild acidity (pH of 2.7), which has a weak etching effect on the acidic functional monomer.[34] Therefore, the higher gap formation (%) observed by SEM at the irradiated dentin–resin interface in the current study may be attributed to the use of self-adhesive material with ultra-mild acidity on a highly acid-resistant dentin surface.

However, the present study showed no significant difference in gap formation (%) at the dentin–resin interface between the irradiated and conventionally prepared groups when examined by μCT. The single-bond universal adhesive used in this study is a radiolucent material that appears as a dark area at the tooth–restoration interface under μCT. Therefore, both thick adhesive layer and gaps between enamel/dentin and resin composite restoration would appear as a gap when observed by μCT. This limitation affects the reliability of μCT analysis when testing the gap formation between enamel/dentin and radiolucent adhesive.

μCT is considered a non-destructive technique that allows for further evaluations of samples. However, μCT analysis is expensive, and μCT magnification is determined by the object distance from the X-ray source: a smaller distance corresponds to higher magnification and more detailed images.[35] SEM, on the other hand, is seen to have an advantage over μCT in terms of image magnification. Rengo et al reported that μCT is as reliable for microleakage assessment as SEM under 20X magnification. However, when samples were observed by SEM with 80X magnification, higher scores of microleakage were reported. The authors concluded that the µCT technique is as reliable as low-magnification SEM, which gives an overview of the entire tooth–restoration interfaces without further details.[35]

In this study, µCT analysis revealed no statistically significant differences in gap formation (%) at the enamel/dentin–resin interfaces of the B and W groups (Table 2). However, SEM analysis demonstrated a statistically higher gap formation (%) at the dentin–resin interface for the W group. Statistically significant higher gap formation (%) means were observed at the enamel/dentin–resin interfaces when samples in the B group were examined by µCT (Tables 4 and 5). SEM is considered a destructive technique that can lead to a loss of information during sectioning and sample preparation. SEM is also time-consuming and provides only 2D views of the sample. Nevertheless, SEM offers detailed images with higher magnifications that allow identifying adhesive and hybrid layers that could not be identified using µCT due to the radiolucency of the used adhesive material. In addition, SEM allows better visualization of the gaps at tooth-resin interfaces that may help to relate the possible cause of gaps to other properties of the used materials. This comes in agreement with Tosco and colleagues' study.[12] Therefore, it can be concluded that SEM analysis provides a more detailed and comprehensive evaluation of the tooth-resin interface and should be used for in-vitro gap formation studies, as it provides clear images of hybrid and adhesive layers that cannot be observed by µCT.

The limitations of this study include the use of one adhesive and one set of parameters for the Er,Cr:YSGG laser (Waterlase Millennium™). Additionally, the use of natural extracted teeth introduces variability in the mineral contents, which results in variations in the outcome. Due to a scarcity of gap formation studies for Er,Cr:YSGG laser-irradiated cavities and a lack of detailed descriptions of laser setting parameters from earlier studies, it is challenging to compare the findings of the current study to those of earlier research. More studies are needed to evaluate gap formation at the tooth–resin interface of cavities prepared by an Er,Cr:YSGG laser for different laser parameters and different types of adhesives.

Conclusion

- When suitable setting parameters are used, using an Er,Cr:YSGG laser for Cl V cavity preparation can be effective.
- In dentin, utilizing an Er,Cr:YSGG laser can result in higher gap formation percentages compared with conventional preparation techniques, which might arise from surface micromorphological and chemical alternations.
- SEM is a more reliable method for gap formation analysis in laboratory studies.

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Conflict of Interests

No conflicts of interest are declared by the authors.

Ethical Considerations

The Institutional Review Board (IRB) of King Saud University gave its approval to this study (project No. E-19-4289) prior to the implementation of the study.

Data Availability

The article includes all data that supports the findings of this in-vitro study.

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