Microleakage in class V cavities prepared using conventional method versus Er:YAG laser restored with glass ionomer cement or resin composite

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Short title: *Effect of tooth preparation method on microleakage of glass ionomers and resin composite*

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Keywords: Dental lasers, Er:YAG laser, glass ionomer, microleakage, resin composite

Introduction

The marginal sealing ability of a restorative material in dentistry may not necessarily correlate with caries formation [1] but development of microleakage over time dictates the longevity of the restoration especially in the visible areas of the anterior region [2]. The use of adhesive resins and minimally invasive methods for tooth restoration has increased during the last decade. However, cervical lesions and marginal staining of the restorations still poses a major challenge [3,4]. Margins of such restorations typically located at the dentin-cementum interface make chemical and/or mechanical union to tooth structures difficult [5].

Resin composite and glass ionomers are commonly used tooth-coloured direct restorative materials indicated for class V cavities [6]. Glass ionomers are biocompatible adhesive restorative materials that have the capacity to bond to tooth structures in addition to releasing fluoride and increases re-mineralization [7-9].

Rotary instruments for tooth preparation have been common armamentarium in dentistry for many decades but they also could cause hypersensitivity due to tactile stimuli [10]. The use of lasers in preparation of dental hard tissues on the other hand had the objective to avoid such problems [11]. Among many laser types, erbium-doped yttrium aluminium garnet (Er:$Y_3Al_5O_{12}$, hereon: Er:YAG) laser at 2.94 μm and the Erbium, Cromium: Yttrium-Scandium-Gallium-Garnet (Er,Cr:YSGG) laser at 2.78 μm have high absorption in water and hydroxyapatite which makes them suitable for cavity preparation [12,13]. Advantages include minimal vibration and noise during cavity preparation and reduced need for local anaesthesia as opposed to conventional rotary systems [14,15]. In terms of surface characteristics of the prepared tooth, Er:YAG laser results in morphology significantly different to that of conventional mechanical

preparation [16]. Irradiated surfaces with Er:YAG laser are characteristically rough, clean, and lack debris. Moreover, the majority of dentinal tubules are reported to be visible and open after this laser treatment, increasing roughness and microretentive pattern [17]. These characteristics are postulated to enhance the retention of restorative materials to dentin [18]. This feature of lasers becomes more essential for restorative materials that have weaker bond to dental tissues such as glass ionomers [19].

Numerous studies have been performed on the effect of Er:YAG laser on the microleakage and adhesion in permanent teeth in conjunction with resin composites [6,7,20,21] but no information is available with the glass ionomers. In fact, compared to conventional bur preparation, the smear layer created with lasers may affect the sealing capacity of glass ionomers depending on their chemical composition and pH [22].

The objectives of this study therefore were to evaluate the effect of tooth preparation method (diamond bur versus Er:YAG laser) on the microleakage levels of glass ionomers and resin composite in class V cavities at both occlusal and gingival regions. The null hypotheses tested were that a) restoration material type and b) cavity preparation method would not affect the microleakage level.

Materials and Methods

Specimen preparation

Human permanent premolars extracted for orthodontic purposes maximum 6 months prior to the study, were selected (N=80). The teeth were intact and free from caries, cracks or any restorations. Soft tissue debris on teeth were removed using hand-scaling instruments, the teeth were cleaned with pumice-water slurry and stored in 0.1% thymol solution for 24 h.

Standard class V cavities were opened using a template on the buccal surface of each

tooth with 3 mm mesio-distal length and 2 mm occluso-gingival height. The depth of cavities was approximately 1.5 mm, determined by a pre-marked periodontal probe. The occlusal margin of the cavity was located on the enamel, and the gingival margin was on the dentin approximately 1 mm below the cemento-enamel junction.

Initially, the teeth were randomly assigned into two groups (n=40) according to the cavity preparation method. Cavities on half of the teeth were prepared using a diamond bur (ISO 001/018 BR-31 Dia-Burs, MANI Inc., Tochigi, Japan) for enamel and carbide bur for dentin under water-cooling with high-speed hand piece using a standard cavity preparation appliance. Positions and dimensions of cavities were standardized through a template prepared in a metal band strip. A new bur was used after every ten cavity preparation. The other half of the tooth was prepared using 2940 nm Er:YAG laser (Fotona Medical Lasers, Fidelis Plus 3 Er:YAG and Nd:YAG Dental Laser, Ljubljana, Slovenia)

Laser irradiation

Er:YAG laser system used had a wavelength of 2940 nm, where the laser was applied under the following conditions according to the manufacturer's recommendations: enamel at 6 W (300 mj, 20 Hz) and dentin at 3W (150 mj 20 Hz) with non-contact hand piece (R02) at a pulse duration of 100 µs, beam spot size of 0.6 mm under continuous water spray (5mL/min). The diameter of the laser beam at tooth surfaces was 2 mm. Output of the laser beam of the laser was focused perpendicular to the tooth surface from a distance of 10mm. Dimensions of prepared cavities were approximately the same as bur-prepared specimens. Prepared teeth were stored in saline solution at 6°C for 24 h until restorative procedures. The cavities were cleaned with a rubber cup (Prophy rubbercup, Diadent, Burlingame, CA) and a pumice-water slurry with low-speed

handpiece.

Restorative procedures

The teeth were then randomly divided into 4 groups to be restored with three glass ionomer cements and one resin composite (n=10 per group). The materials used in this study are presented in Table 1. All cavities were prepared and restored by the same operator. The manufacturer's instructions were followed for dentin conditioning, application, and restoration and finishing.

Application procedures were as follows:

ChemFil™ Rock (CFR)-Glass ionomer

The glass ionomer capsule (ChemFil™ Rock) was activated by pressing the plunger. After activation, the capsule was placed in a mixer (4300 cycles/min, Silver Mix 90, Blackwell Supplies Ltd, London, UK) for 15 s. The capsule was then removed and placed immediately into the extruder (Capsule Extruder2, Dentsply, DeTrey GmbH, Konstanz, Germany) then dispensed into a cavity. The excess material was removed using bonding brush applicator. Finally, abrasive discs (Soflex Disks, 3M ESPE, Minnesota, USA) were used for finishing and polishing. After 24 hours of water storage at 37°C, the restorations were finished and polished with aluminum oxide abrasive discs (Soflex Disks, 3M ESPE, Minnesota, USA).

IonoluxAC (IAC)-Glass ionomer

The capsule (IonoluxAC, Voco, Cuxhaven, Germany) was inserted into the capsule activator. The lever of the activator was pressed and held for 2 s. As described above, the activated capsule was mixed for 10 s. The material was applied to the cavity, shaped, and photo-polymerized for 20 s (Bluephase C5, Ivoclar, Vivadent, Schaan, Liechtenstein). The excess material was removed using bonding brush applicator and

the finishing and polishing steps were performed using abrasive discs as described for group CFR.

EQUIA (EQA) system-Glass ionomer

Cavity conditioner (GC Corporation, Tokyo, Japan) was applied for 10 s using a cotton pellet and rinsed thoroughly with copious water. Before activation, the capsule (Fuji IX GP Extra) was agitated to loosen the powder. The material was mixed for 10 s and then immediately inserted into the cavity. Finishing and polishing steps were performed using abrasive discs as described for group CFR. Thereafter, G-Coat (GC Corporation) was applied with a microbrush on the restoration surface and photo-polymerized for 20 s. Finishing and polishing steps were performed using abrasive discs as described for group CFR. AELITE™ LS (ALS)-Posterior resin composite

Cavities were etched with 32% phosphoric acid (UNI-ETCH, Bisco, Inc., Schaumburg, USA) for 15 s and treated with two consecutive coats of adhesive resin (ONE-STEP® PLUS, Bisco, Inc.). The adhesive resin was photo-polymerized for 10 s before restoration (AELITE™ LS, Bisco, Inc.). Restoration was placed into cavity employing incremental layering technique. The finishing and polishing steps were performed immediately following polymerization with abrasive discs as described for group CFR.

Dye penetration and microleakage measurement

The restored teeth were stored in deionized water at 37°C for 24 h. The teeth were then subjected to 500 thermal cycles in water baths at 5-55±2ºC with a dwell time of 30 s and transfer time of 3 s [23-25]. After thermocycling, teeth were stored in distilled water at 37°C for 24 h to prevent dehydration.

Microleakage was evaluated using a conventional dye penetration method. The specimens were immersed in 0.5% basic fuchsine for 24 h for dye penetration. Each

specimen was sealed with two coats of nail varnish leaving a 1 mm window around the cavity margins. The teeth were then sectioned in buccolingual direction along the restoration centre using a slow-speed diamond saw (Isomed 1000 Precision saw, Buehler Ltd, Lake Bluff, IL) mounted in diamond wafering blade (6'' Dia. × 0.20'' Buehler Ltd) under running water.

The length of microleakage zone (μm) was then measured at the occlusal and gingival margins. Dye penetration at the occlusal/enamel and gingival/dentin margins toward the axial wall was recorded at an accuracy of 0.1 mm using a calibrated ocular scale. Microleakage was scored using a 3 scale scoring system (Table 2) [26,27]. Two observers (FEG and BD) blinded to the restorative procedures, examined the specimens. Two sections per tooth were examined, and scores for the occlusal/enamel and gingival/dentin margins were analyzed. Only the section with the most microleakage from each specimen was used for scoring.

Statistical analysis

Descriptive statistics were computed and test of normality was performed using Kolmogorov-Smirnov test. Some microleakage values were not normally distributed because of this reason nonparametric test was used. In each restorative material type (4 levels: CFR, IAC, EQA, ALS) group, microleakage values comparisons between the cavity preparation method (2 levels: diamond bur and Er:YAG) for occlusal and gingival margins and in each cavity preparation method for each restorative material type groups microleakage values comparisons between the occlusal and gingival margins were analysed using the Mann Whitney U test. In each the occlusal and gingival margins for the combination of each cavity preparation method and each restorative material type group's comparisons were performed using Kruskal-Wallis test. When significant difference was observed ($p<0.05$), the Dunn-test was used for multiple comparisons.

The intra-class correlation coefficient (ICC) for microleakage values and weighted kappa for microleakage scores were calculated to assert inter-observer agreement. *P* values less than 0.05 were considered to be statistically significant. All statistical analyses were performed using SPSS 13.0 for Windows, SPSS Inc., Chicago, IL, USA.

Results

All weighted kappa agreements for bur treatment groups, with the exception of CFR (gingival: 0.542), were greater than 0.88. Except for IAC (gingival: 0.667) and the EQA (occlusal: 0.5), all weighted kappa agreements in the laser treatment groups were greater than 0.8. These results indicate strong agreement of microleakage scores between the two observers. ICCs were greater than 0.70, with the exception of the IAC-bur (occlusal: 0.4624) and CFR-laser (gingival: 0.6567) combinations. These results also indicate strong agreement of microleakage values between the two observers.

On the occlusal aspect, while the cavity preparation types significantly affected the microleakage for CFR (p=0.0115), IAC (p=0.001) glass ionomer restorations, it did not show significant effect for glass ionomer EQA (p=0.09) and resin composite ALS (p=0.2) (Table 3). Er:YAG laser presented less microleakage compared to bur preparation in all groups except for EQA.

On the gingival aspect, microleakage decreased significantly for CFR (p=0.02), IAC (p=0.001), except for EQA where significant increase was observed (p=0.001) with the use of Er:YAG laser (Table 3). Microleakage decrease was not significant at the gingival region between diamond bur and Er:YAG laser for ALS (p=0.663).

At the occlusal and gingival sites in all groups within each preparation method, microleakage level was not significant (Table 4).

Discussion

This study was undertaken in order to find out whether the use of Er:YAG laser would be an alternative to conventional diamond burs in order to decrease microleakage for restorations made of glass ionomers and resin composite in class V cavities. Based on the results of this study, since cavity preparation method affected the microleakage levels depending on the material type, the null hypothesis could be partially accepted.

Thermal expansion coefficient differences between dental tissues and the restorative materials, or shrinkage due to cavity configuration factors may cause gap formation at the tooth-restoration interface [2]. Especially, in class V restorations, microleakage is one of the most frequently encountered problems [3]. A strong correlation has been reported between contraction stress values at the bonded interface and microleakage levels [28]. In the present study, the gingival margins of cavities were located in dentin while the occlusal margins in enamel. Adhesion to the gingival dentin wall is generally less adequate than to enamel yielding to more microleakage in dentin [17]. However, in this study, at the occlusal and gingival sites within each preparation method for each material, level of microleakage varied depending on the material yet being not significant between these two sites. This indicates that not only adhesion but also parameters such as viscosity, chemistry, pH of the restoration material may contribute to the degree of microleakage. For the IAC glass ionomer, after both bur and laser treatments at the gingival site, microleakage was higher compared to the occlusal site but again the difference was not significant.

In principle, glass ionomer cements adhere to dental structures through chemical adhesion when the carboxylic groups of cement bind to tooth calcium ions [29]. Better marginal adaptation of glass ionomers to enamel compared to dentin supports the findings of previous studies [20,30]. This is due to the relative amounts of hydroxyapatite

available for ionic bonding on the enamel site [31]. Glass ionomers also possess coefficient of thermal expansion close to that of the tooth structures and present low setting shrinkage [29]. This provides eventually good marginal sealing, minimal microleakage at the restoration/tooth interface and thereby high retention rate [17]. Interestingly however, IAC and CFR glass ionomer cements presented less microleakage in the laser group compared to bur treatment. On the other hand, the other glass ionomer EQA, did not benefit from laser treatment and presented even increased microleakage. In the current study, the manufacturer's instructions were followed strictly. Additional cavity conditioner application was not recommended for CFR and IAC but for EQA. Cavity conditioner provided for this product is composed of aqueous polyacrylic acid with aluminium chloride. While the aluminium chloride acts as a wetting promoter, polyacrylic acid provides the carboxyl group for hydrogen bonding, which is then displaced by the stronger interaction of polar and ionic attraction from the glass ionomer setting reaction [9]. Apparently, pre-treatment of bur-prepared cavities with the conditioner in the EQA system significantly improved the marginal adaptation compared to the CFR and IAC groups, which were not treated with dentin conditioner. It has to be noted that there were no microleakage when the cavities were prepared with conventional diamond burs, which were subsequently filled with EQA. This could be caused by the morphological characteristics of the preparation surface. The conventional bur preparation creates a thicker smear layer, which could impair adhesion of the restoration material [21]. On the contrary, low microleakage scores in laser-treated teeth could be related to the morphology of the dentin following irradiation. The surface ablated with Er:YAG laser irradiation has been reported to be free of a smear layer and the dentinal tubules demonstrated a scaled intertubular region that increased the area of exposed intertubular dentin [32,33]. Future studies should investigate on the

morphological changes on enamel and dentin after the application of the glass ionomer cements used in this study on laser treated surfaces.

For conventional glass ionomer cements, adhesion is the result of an intimate contact between restorative material and tooth substrate so a surface lacking a smear layer is a condition *sine qua non* [34-37]. The effect of polyacrylic acid conditioner, which is a weak acid on Er:YAG laser prepared tooth surfaces has not been clearly defined. According to the manufacturer's instructions, the cavity conditioner used prior to the application of EQA is 20% polyacrylic acid. The results clearly demonstrate that Er:YAG laser prepared cavities have less microleakage than bur-prepared cavities for the EQA system. This may be caused by the modified composition of intertubular dentine following laser irradiation. This modification could lead to a dentin surface more resistant to demineralization, impairing the action of polyacrylic acid conditioner. This result was in disagreement with Delme et al. [7] who reported that conditioning of laser prepared dentin with cavity conditioner resulted in a smooth surface with partial occlusion of dentinal tubules and may improve contact between the glass ionomer and tooth surface. The diversity of the results may be due to differences in the physical parameters of the laser such as type of laser, duration of exposure, and energy applied to the surface. Further studies are warranted to better understand the structural alterations from conditioning tooth surfaces prepared by Er:YAG laser as well as the effects on the mechanisms of adhesion of glass-ionomers to irradiated enamel and dentin. Also, the adhesive interface micromorphology and the alterations in substrate compounds following Er:YAG laser treatment should be determined [24].

It has to be noted that the viscosity of the filling material also plays a role in microleakage [20]. The results of the present study relating to EQA system were similar to those of a previous study [20] where smooth dentin with open tubules of a

conventionally prepared and conditioned surface resulted in a better seal than laser abblated surfaces for EQA system. The high viscosity of the EQA however impedes the adaptation to the irregular dentin walls, angles, and margins cut by laser [36]. For standardization purposes, caries-free teeth were used since extension and depth of caries could not be controlled in caries-affected teeth. The effect of the methods tested should be verified also on caries-affected teeth.

In this study, especially after bur treatment differences between materials were evident. The photo-polymerized glass ionomer cement IAC, showed more leakage than all other groups. On the other hand, zinc-reinforced glass ionomer CFR showed more leakage than EQA. However, glass ionomer EQA, which is an improved version of conventional glass ionomer, behaved similarly to that of the resin composite ALS. Composite resins are considered as suitable materials for direct restorations including restorations of class V cavities, in particular due to their good esthetic results. Nonetheless, a major problem with class V resin composites remains to be microleakage along the cervical wall in these restorations, which is considered as a major problem in restorative dentistry [38]. Thus, composite resin was considered as a control group representing a more aesthetic material compared to glass-ionomer. It also has to be emphasized that the types of glass-ionomer materials used in this study have different application modes. Thus, pre-treatment and application of the restorations varied in accordance with each manufacturer's instructions that might have had an effect on the variation in the results.

In this study, different Er:YAG laser parameters were not practiced during cavity preparation as the manufacturer's instructions were complied which can be considered as a limitation of this study. Further *in vitro* and *in vivo* research into the quality of glass ionomer cements and composite resin in Er:YAG laser prepared cavities is needed in order to develop an adhesive protocol and justify whether there is need for the use of

laser at all. Laser devices are costly armamentarium to be used in general practice. Yet, practitioners and especially paediatric dentists could benefit from such innovative devices especially by non-compliant patients, fearing from rotary instruments. Their advantages need to be warranted before they substitute conventional rotary instruments.

Conclusion

From this study, the following could be concluded:

1. On the occlusal and gingival aspects, less microleakage was observed with Er:YAG laser compared to conventional diamond bur preparation.
2. Occlusal and gingival sites showed no microleakage for EQA with conventional diamond bur.
3. At the occlusal and gingival sites for each preparation method similar levels of microleakage were observed with all materials tested.

Disclosure statement

The authors did not have any commercial interest in any of the materials used in this study.

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Captions to Legends:

Tables:

Table 1. Brands, abbreviations, manufacturers, types and chemical compositions of the materials used in this study.

Table 2. Criteria for microleakage scores at the tooth-restoration interface.

Table 3. Depths of dye penetration (μm) at the occlusal and gingival margins.

Table 4. Statistical comparison of occlusal and gingival microleakage values between experimental groups. Same lowercase superscript letters in each row, and same uppercase letters in each column indicates no significant difference (Kruskal Wallis, $\alpha=0.05$).

Tables:

Brand	Manufacturer	Type	Chemical Composition
ChemFil™Rock (CFR)	Dentsply, DeTrey GmbH, Konstanz Germany	Advanced Glass Ionomer Restorative	Calcium-aluminium-zinc-fluoro-phosphor-silicate glass, Polycarboxylic acid, Iron oxide pigments, Titanium dioxide pigments, Tartaric acid and Water
IonoluxAC (IAC)	VOCO GmbH, Cuxhaven, Germany	Conventional Glass Ionomer	Polyacrylic acid, Fluorosilicate glass, Amines, BHT and Methacrylates
EQUIA system (EQA)	GC Corporation, Tokyo, Japan	Conventional Glass Ionomer	Fuji IX GP Extra: 95% Alumino silicate glass, 5% Polyacrylic acid powder G-Coat: Methyl methacrylate, colloidal silica, camphorquinone, urethane methacrylate, phosphoric ester monomer
AELITE™ LS (ALS)	BISCO, Schaumburg, IL	Posterior Composite Resin	Ethoxylated bis-GMA, Glass filler, Amorphous silica

Table 1. Brands, abbreviations, manufacturers, types and chemical compositions of the materials used in this study.

Score	Criteria
0	No microleakage; no dye penetration.
1	Microleakage observed only at the enamel cavity wall; dye penetration through the cavity margin reaching the enamel or cementum.
2	Microleakage observed at the dentine cavity wall but not on the cavity floor; dye penetration through the cavity margin reaching the dentin.
3	Microleakage observed on the cavity floor; dye penetration through the cavity margin reaching the cavity floor.

Table 2. Criteria for microleakage scores at the tooth-restoration interface.

Experimental Groups	Preparation	Occlusal depth of dye penetration (µm) Median (range: min;max)	*p*	Gingival depth of dye penetration (µm) Median (range: min;max)	*p*
CFR	Bur	716.9 (0;4227.2)[a]	0.0115	2395(0;4221.2)[a]	0.002
	Laser	0 (0;722.02)[b]		0 (0;177.87)[b]	
IAC	Bur	1280.1 (546.14;2330.8)[a]	0.001	2007.3 (688.91;3474)[a]	0.001
	Laser	404.99 (0;1138.4)[b]		504.96 (0;1987.7)[b]	
EQA	Bur	0 (0;0)[a]	0.09	0 (0;0)[a]	0.001
	Laser	128.66 (0;999.77)[a]		455.77 (0;950.86)[b]	
ALS	Bur	0 (0;560.17)[a]	0.2	0 (0;488.93)[a]	0.663
	Laser	0 (0;0)[a]		0 (0;0)[a]	

Table 3. Depths of dye penetration (µm) at the occlusal and gingival margins.

Margin	Bur + CFR **Median (min;max)**	Laser + CFR **Median (min;max)**	Bur + IAC **Median (min;max)**	Laser + IAC **Median (min;max)**	Bur + EQA **Median (min;max)**	Laser + EQA **Median (min;max)**	Bur + ALS **Median (min;max)**	Laser + ALS **Median (min;max)**
Occlusal	716.9 (0;4227.2)^{A}	0 (0;722.02)^{A}	1280.1 (546.14;2330.8)^{A}	404.99 (0;1138.4)^{A}	0 (0;0)	128.66 (0;999.77)^{A}	0 (0;560.17)^{A}	0 (0;0)
Gingival	2395(0,4221.2)^{A}	0 (0;177.87)^{A}	2007.3 (688.91;3474)^{A}	504.96 (0;1987.7)^{A}	0 (0;0)	455.77 (0;950.86)^{A}	0 (0;488.93)^{A}	0 (0;0)
p	0.21	0.9	0.2	0.6	~1	0.11	0.068	~1

Table 4. Statistical comparison of occlusal and gingival microleakage values between experimental groups. Same lowercase superscript letters in each row, and same uppercase letters in each column indicates no significant difference (Kruskal Wallis and Mann Whitney U test, α=0.05).