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The Effect of Different Techniques of Enamel Etching on the Shear Bond Strengths of Fissure Sealants

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Abstract

The aim of this study was to evaluate effect of different techniques of enamel etching on shear bond strengths (SBS) of fissure sealants. Fifty extracted non-carious third molars were cleaned with fluoride-free pumice and root sections 2mm below cementoenamel junction were taken. Coronal sections were embedded in resin, and buccal/lingual surfaces of crowns were flattened to create an enamel surface area that was 3mm in diameter. The specimens were randomly assigned to 1 of 5 groups with 10 teeth each. Group1 35% orthophosphoric acid–etching (20sec); Group2 a fissurotomy–bur (Fissurotomy Micro–NTF); Group3 Erbium, Chromium:yttrium-scandium-galliumgarnet (Er,Cr:YSGG) laser 2W laser etching (20sec–20Hz); Group4 Er,Cr:YSGG laser 2W laser etching (20sec–40Hz); and Group5 20sec air-abrasion with 30µm Al_2O_3 particles Cojet–Prep. Cylindrical-transparent-gelatin tubes (diameter:3mm–height:2mm) were placed on substrate surfaces. Further, sealants were applied and cylinders of fissure sealants were submitted to an SBS test in a universal testing machine with a crosshead speed of 0.5 mm per second. The data were analyzed by means of one-way analysis of variance and Tukey's post-hoc tests ($p<0.05$). The SBS values (mean±SD–MPa) were obtained as Group1 (8.47±1.30)>Group4 (5.99±1.36)> Group3 (5.27±1.56)>Group5 (2.02±0.86)>Group2 (1.65±0.69). Group1 exhibited significantly higher SBS values compared to other groups. Group4 resulted in higher SBS values compared to Group3, although no significant differences were found. No significant differences were observed between Groups2 and 5. It can be concluded that, compared with conventional enamel acid–etching, laser 2W–20Hz/40Hz may have an advantage in improving SBS values of fissure sealants compared to Cojet–Prep and fissurotomy–bur techniques.

Keywords: Er,cr:ysgg laser; Cojet-prep; Fissurotomy-bur; Etching; Fissure sealant

Introduction

Pit and fissure sealants are an outstanding adjunct to oral health preventive strategies in the decrease of occlusal caries onset and/or progression. The properties of an ideal sealing material include biocompatibility, retention, and resistance to abrasion and wear [1]. The success rate of fissure sealants depends on factors, such as retention and resistance to shear bond strength (SBS) associated with the quality of the adhesion between the sealant material and the enamel [2]. Prior to sealant application, it is important that the tooth surface and fissure areas are free of gross plaque and debris that might interfere with sealant penetration [3]. The use of phosphoric acid is a well-accepted and standard method for roughening enamel surfaces. However, remaining debris and pellicle might not be removed by means of conventional prophylaxis and acid etching. Therefore, several preparations and cleaning techniques used on the tooth surface before sealant application have been suggested [4].

A widening of the fissures with rotary instrumentation is yet another type of fissure conditioning that has been recommended prior to sealant application. This is known as the invasive pit-and-fissure technique used to clean the fissure entrance, permit inspection of incipient caries, and determine the degree of possible caries extension toward the dentinoenamel junction. Results of clinical studies have been encouraging for caries prevention, but they do not conclusively support the routine practice of fissure preparation before sealant application [3-7]. There is limited and conflicting evidence that mechanical preparation with a bur results in higher retention rates in children [8].

Also suggested for the preparation of the occlusal surface prior to sealant application, air abrasion, has become more popular with the advent of minimally invasive dentistry [3,4,6]. This method uses airborne-particle abrasion with silica-modified Al_2O_3 particles in conjunction with silanization (Cojet-Prep, 3M ESPE, Seefeld, Germany). It is propelled by air pressure to abrade the tooth surface. Cojet-Prep has a particle size of 30-50micrometers, is applied in a single step, and is indicated for chairside application with the use of a chairside air abrasion device. Cojet-Prep can remove debris and excavate incipient decay in the fissures. Moreover, some researchers have suggested that they can prepare the enamel surface for fissure sealant, eliminating the acid application and rinsing steps [7]. There is limited and inconclusive evidence in favor of using air abrasion as a cleaning method before acid etching to improve sealant retention [8].

Laser devices have been used in dentistry for soft tissue surgery, root-end sealing and disinfects, and enamel/dentin surface alteration to increase resistance to decay or facilitate the bonding of composites [9]. Laser etching may be an alternative to acid etching of enamel and dentin. It might also yield anfractuous surface and open dentin tubules, both of which are apparently ideal for adhesion. Another advantage of laser etching is its production of acid-resistant surfaces [10]. Laser irradiation of dental hard tissues modifies the calcium-to-phosphorus ratio, reduces the carbonate-to-phosphate ratio, and leads

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to the formation of more stable and less acid-soluble compounds, thus reducing susceptibility to acid attack and caries [11].

In recent years, the etching efficiency of carbon dioxide (CO_2), neodymium: yttrium-aluminium-garnet (Nd: YAG), erbium:yttrium-aluminium-garnet (Er: YAG), and erbium,chromium:yttrium-scandium-gallium-garnet (Er, Cr: YSGG, Waterlase MD, Biolase Technology Inc.; San Clemente, CA, USA) lasers on tooth surfaces has been evaluated in many studies using leakage and mechanical tests [2,12-15]. Within these laser systems, the Er, Cr: YSGG laser is the most promising in paediatric dentistry. Moreover, it has the advantage of working on hard and soft tissues without anaesthesia. The conditioning effects of the Er, Cr: YSGG laser on dental hard tissues have been investigated by numerous researchers via microleakage evaluation and mechanical tests conducted on composite restorations applied to primary and permanent tooth cavities [2,13]. Considering these facts, the use of the Er, Cr: YSGG laser in fissure sealing is of increasing interest.

There are no studies examining and comparing conditioning performed with laser, air abrasion, fissurotomy and acid-etching separately. Consequently, the purpose of this in-vitro study was to evaluate the effect of different techniques of enamel etching on the SBS of resin-based fissure sealants in molar teeth.

Materials and Methods

Fifty partially or totally impacted human mandibular third molar teeth, free of caries and without any other microscopic defects, were assigned for extraction and extracted after obtaining the informed consent form signed by the patients, as this was an *in vitro* study. The teeth were stored in distilled water at 4ºC for a maximum of one month. To prevent bacterial growth, the water was changed weekly. After surface debridement with hand scaling instruments and cleansing with a slow-speed hand piece and a brush with a fluoride-free pumice, root sections 2 mm below the cementoenamel junction were taken. The crowns were bisected longitudinally in a mesiodistal direction and the buccal and lingual surfaces were selected for experimentation. Coronal sections were embedded in polyester resin and the surface of each specimen was polished using 200-grit and 600-grit silicon carbide paper in a mechanical grinder (EcoMet®, Buehler®, Lake Bluff, IL, USA). The overlying enamel was flattened to create an enamel surface area of 3 mm in diameter. The specimens were randomly assigned to 1 of 5 groups with 10 teeth each (Table 1).

For the acid-etching procedure (Group 1), the enamel buccal/lingual surfaces of the teeth were first air dried and then etched for 20 sec with a 35% orthophosphoric acid gel (Scotchbond™ etchant delivery system, 3M ESPE, St. Paul, USA) rinsed for 15 sec and air dried for 10 sec. 3 mm diameter etched enamel surface was obtained.

For the enameloplasty procedure (Group 2), the enamel buccal/lingual surfaces were prepared using fissurotomy-bur (Fissurotomy Micro NTF, New Jersey, USA). 3 mm diameter prepared enamel surface was obtained.

Group no	Surface pretreatment
1	35% orthophosphoric acid etching
2	Fissurotomy-bur (Fissurotomy Micro NTF)
3	2W-20 Hz Er,Cr:YSGG laser irradiation
4	2W-40 Hz Er,Cr:YSGG laser irradiation
5	Al_2O_3 particle size of 30micrometer Cojet-Prep

Table 1: The enamel buccal/ lingual surface pretreatment methods.

For the laser procedure (Groups 3 and 4), laser etching was completed with an Er, Cr: YSGG laser system (Waterlase MD, Biolase Technology Inc., San Clemente, CA, USA) operating at a wavelength of 2,780 nm and having a pulse duration of 140-200 microsecond with a repetition rate of 20 Hz and 40 Hz. Laser energy was delivered through a fibreoptic system to a sapphire tip terminal that was 600 micrometers in diameter and 6 mm in length. The power output was set at 2 W according to the study group. Air and water spray from the handpiece was adjusted to a level of 85% air and 85% water for 2 W to prevent the enamel surfaces from overheating. Moreover, the average exposure time was set at 10 seconds. 3 mm diameter prepared enamel surface was obtained.

For the Cojet-Prep (3M ESPE, Seefeld, Germany) procedure (Group 5), the enamel surfaces were coated in silica. In addition, the devices abraded the specimens for 20 sec with a Al_2O_3 particle size of 30 micrometers. 3 mm diameter prepared enamel surface was obtained.

Following these procedures, cylindrical transparent gelatin tubes (Tygon Micro Bore PVC Tubing, Small Parts, Miami Lakes, FL, USA) (diameter of 3 mm and height of 2 mm) were placed on substrate surfaces. Further, resin-based fissure sealants (ClinPro™, 3M Dental Products, St. Paul, USA) were applied, and the sealant was handled according to the manufacturer's instructions. It was light-cured for 40 sec (Curing light XL 3000™, 3M Dental Products, St. Paul, USA), and the matrix was subsequently removed. After storing the specimens for 24 h in distilled water at 37ºC, we tested them in shear mode by using a shear knife-edge blade in a universal testing machine (Instron Corporation, Canton, MA, USA) with a crosshead speed of 0.5mm/second. We calculated the SBS in megapascals using the following formula:

$$\frac{\text{peak load at failure}\ (\text{newtons})}{\text{specimen bonding surface area}\ (\text{mm}^2)} = \text{strength of shear bond}$$

Results were recorded and analyzed using SPSS 14.0.0 for Windows (SPSS Inc., Chicago, IL, USA). We compared the mean bond strengths using a one-way analysis of variance and Tukey's post-hoc tests ($p<0.05$).

Results

Table 2 presents the mean SBS and standard deviations for all groups. The following SBS values (mean±SD values-MPa) were obtained: Group 1 (8.47±1.30) > Group 4 (5.99±1.36) > Group 3 (5.27±1.56) > Group 5 (2.02±0.86) > Group 2 (1.65±0.69). Group 1 exhibited significantly higher SBS values compared to the other groups. Group 4 had higher SBS values than Group 3, although no significant differences were found. In addition, no significant differences were observed between Groups 2 and 5.

Discussion

It is recognized that studies examining the various alternative roughening methods to the acid-etch technique used for surface roughening necessary for the adhesion of fissure sealants to the enamel surface are limited. Therefore, the bonding strength of fissure sealant materials on enamel was analyzed with an SBS test and the effect of various enamel etching applications on bond strength was investigated.

Surface Pretreatment Method		Shear Bond Strength (MPa#)		*P* Value				
	n	Mean ± SD##	Range	Group 1	Group 2	Group 3	Group 4	Group 5
Group 1	10	8.47±1.30	6.71-10.85	Not applicable	.000*	.000*	.005*	.000*
Group 2	10	1.65±0.69	0.47-2.73	.000*	Not applicable	.000*	.000*	>.979
Group 3	10	5.27±1.56	3.67-8.50	.000*	.000*	Not applicable	>.792	.000*
Group 4	10	5.99±1.36	4.21-8.12	.005*	.000*	>.792	Not applicable	.000*
Group 5	10	2.02±0.86	0.86-3.04	.000*	>.979	.000*	.000*	Not applicable

#MPa: Megapascals
##SD: Standard deviation
*$P < .05$

Table 2: Desciptive statistics and post hoc test results for all groups.

The success of sealant bonding depends on both the forces of mechanical interlocking between the resin tags and the enamel and the stresses appearing at the interface [16]. Strength testing is a laboratory method used to evaluate the adhesion capacity of dental materials to tooth surface. A SBS test provides insight into the adhesion of these materials and serves as a screening mechanism for predicting clinical performance [5]. In an attempt to improve the retention of sealants, investigators in a number of studies have examined the influence of occlusal surface preparation on SBS or microleakage of pit-fissure sealants with a bur [16,17], air abrasion [6,18], and laser irradiation [1,17,19].

Phosphoric acid is one of the best methods to bond resins to enamel. The smear layer is removed by applying acid on the enamel surface. Microscopic roughness and enamel surface energy are enhanced by removing prismatic and interprismatic mineral crystals. Generally, 10-37% orthophosphoric acid is applied to both the enamel and the dentin [3,20]. In this study, we used a 35% orthophosphoric acid gel and found that acid etching was the application that led to the highest SBS.

Currently, laser etching of enamel surfaces is popular because of the potential disadvantages of acid etching. Acid etching results in chemical changes that can modify the organic matter and decalcify the organic component. As a result of this demineralization, enamel becomes more susceptible to caries attack, which is induced by plaque accumulation around the bonded fissure sealant [2,12,13,21,22]. Hossain [23] reported an increase in the calcium-to-phosphorus ratio achieved during laser irradiation that resulted in caries inhibition.

Another enamel treatment method is an air-abrasion system, Cojet-Prep. It has several advantages. It is harmless on soft tissues. In addition, it allows patients to overcome dental phobia because of reduced pain. Further, there is no heat, vibration, pressure, noise, or smell produced during treatment. It is non-traumatic and prevents microfractures due to heat and vibration. Fınally, it reducces microleakage due to a better adaptation between cavity walls and the material [3,6,7,24-26]. Knobloch [26] examined the effect of air abrasion, acid etching (37% phosphoric acid), and air abrasion together with acid etching as surface preparation techniques on the bond strength of the resin-based fissure sealant. They found that air abrasion together with acid etching enhanced the bonding strength of the resin-based fissure sealant. Moslemi [4] reported that the pretreatment of the enamel surface with air abrasion increased the bond strength of the fissure sealant; however, pretreatment with a Er, Cr: YSGG laser did not increase the effectiveness of conventional acid ecthing of enamel in sealant bonds. Hatibovic-Kofman and Koch [25] found that air abrasion alone was clinically insufficient. These findings align with those of this study.

Bur preparation is another application for enamel surface treatments. Fissure sealant application following fissure preparation with the invasive technique enhances retention. There are special fissurotomy burs that achieve this goal. It is well known that the smear layer that forms after the preparation of the enamel surface with burs plays a critical role in bonding the adhesive restorations to the tooth [7,27]. Geiger [28] applied fissure sealant to non-carious permanent teeth in which surface preparation techniques, carbide burs, an angled diamond bur, and 37% phosphoric acid were used. They found that the diamond bur together with acid etch increased the penetration of the fissure sealant.

In this study, the lowest SBS were observed in the bur group (Group 2), possibly because of the smear layer that formed following bur preparation on the enamel surface. Therefore, studies were performed to examine whether surface treatment methods caused the formation of the smear layer. A thick and compact smear layer formation during preparation with burs were found in several studies as well as in this study [7,28,29].

When the effects of Er, Cr; YSGG lasers on dental tissues were examined, cavities were found to be unaffected by thermal damage. This pattern may enhance the bonding of adhesive restorations [2,11-15,21,30]. The literature contains conflicting findings regarding surface treatments and cavity preparations with lasers. One laser used for this purpose is Er, Cr: YSGG, which has a high absorbsion coefficient in water and enamel. This led researchers to explore its use in enamel conditioning. For cutting enamel, the clinician can use high-irradiation outputs varying from 2.5 to 6 W. In this study, we used a lower output 2W to etch the enamel. Recently, Berk [31] observed by means of a scanning electron microscope (SEM) analysis that 1 W, 1.5 W, and 2W Er, Cr: YSGG laser irradiation produced etching patterns similar to those of acid etching.

Several of the findings concerning the use of lasers for enamel etching are contradictory. Some researchers stated that laser irradiation was not capable of etching enamel. Martines-Insua [12] found weaker adhesion forces in a Er: YAG laser-etched enamel surface than an acid-etched enamel surface. This was related to sub-surface cracks observed in SEM images. Tarcin [32] found that the microtensile bond strength was significantly lower in the acid-etched group than the Er, Cr: YSGG and Nd: YAG laser-etched enamel group for both bonding agents used. Borsatto [15] and Lupi-Pegurier [16] both verified that Er: YAG laser irradiation did not eliminate the need to etch the enamel surface with acid before applying the sealant. Usumez [21] stated that Er, Cr: YSGG laser-etching techniques were not a sufficient method to enhance the adhesion to enamel in bonding stainless steel orthodontic brackets when compared with acid-etching techniques.

The results of this study indicate that laser-etching techniques results in a weaker bond strength compared with acid-etching techniques. On the other hand, some researchers stated that laser applications give similar results to acid-etching techniques. Ozer [33] investigated the SBS of brackets that they applied on enamel prepared with 0.75 W Er, Cr: YSGG, 1.5 W Er, Cr: YSGG, 37% orthophosphoric acid, or self-etching primer. They found that the 0.75 W laser-applied group was significantly less in regard to SBS than all other groups, although there was no statistically significant difference among the other groups. Manhart [17] and Lepri [1] reported that if Er: YAG laser conditioning was followed by acid etching, the retention of the sealant would be equal to that achieved with acid etching alone. Basaran [34] compared the SBS of brackets using a Er, Cr: YSGG laser in 0.5W, 0.75W, 1W, 1.5W, 1.75W, and 2W. They stated that 1.5W, 1.75W, 2W, and 15 sn etching yielded similar success rates as 38% phosphoric acid etching. Kim [35] investigated the microtensile bond strength of brackets on enamel etched with a Er: YAG laser or acid and found no statistically significant difference between the two etching methods.

Lee [1] etched enamel surfaces with acid, a laser, and acid and a laser together and investigated the SBS of the orthodontic brackets. They did not find statistically significant differences in the laser- and acid-etched surfaces. Further, they reported that the application of both could enhance the bond strength. Sungurtekin and Oztas [2] noted that Er, Cr; YSGG laser etching did not eliminate the need for acid etching. Moreover, they found that when a Er, Cr: YSGG laser and acid etching were combined, Er, Cr: YSGG was as effective as the conventional acid-etching technique. Further, results of a study on the microtensile bond strengths of porcelain veneers bonded to tooth surfaces showed similar values, regardless of whether the teeth had been treated with a Er, Cr: YSGG laser or 37% orthophosphoric acid [11]. Because the handpiece of the Er, Cr: YSGG laser is light, its manipulation is easy. In addition, the clinician has more control of the area to be etched.

Frequency in laser units connotes for how many seconds the pulse creates the wave. The unit of frequency is the hertz (Hz). A laser with a wide spectrum of frequencies was used in our study because of its clinical feasibility [36]. Another advantage of the Er, Cr: YSGG laser is that the frequency setting are adjustable. Studies examining the frequency settings are generally aimed at evaluating thermal increments. There were no studies investigating 40 Hz setting, according to the literature review. Freitas [37] investigated the properties of the enamel surface of cavities prepared with burs or the Er: YAG laser with different parameters (160 mJ, 15 Hz, 180 mJ, 15 Hz) under SEM. They reported no change related to thermal changes, such as carbonization or melting, and an interprismatic glassy pattern and transverse enamel prisms formed in both energy levels. Lin [9] used a Er, Cr: YSGG laser with SEM and investigated the preparation effect of the laser (6 W, 20 Hz, air and water cooling) and bur. They reported that there was a smear layer on the surface prepared with the bur. Further, the prismatic structure of enamel was not clearly seen. Finally, the surface that was prepared with the laser was clear, had no smear layer, and had a prismatic structure.

Delme [38] etched the prepared cavities with either a Er: YAG laser (400 mJ, 12 Hz, air and water cooling) and bur or a laser (100 mJ, 10 Hz) and acid. They investigated the morphological changes that occurred in the enamel and the dentin surfaces under SEM. They reported the key pattern in the laser-prepared enamel surface: rounded edges in the laser treatment after laser preparation and more retentive indentations in the acid etch after laser preparation than in the laser group. Dunn [39] investigated the enamel surfaces prepared with bur and a Er: YAG laser in an in-vitro study. They found a mixed etching effect in the bur-prepared and acid-etched groups and indentations with surface ablation in the laser-prepared group (140 mJ, 30 Hz). One type of microindentation occurred in the laser-prepared, acid-etched group. Although there was no statistically significant difference between the 2W 40 Hz laser and the 20 Hz laser SBS was found to be higher. Also, there was no smear layer, melting, or carbonization in any of the laser groups.

Laser etching might be an alternative to acid etching because water and organic components are removed, reducing the risk of secondary caries. It is well known that physicochemical changes occurring after laser etching made the tooth more resistant to acid attacks and caries in the long term. Moreover, this caries reduction phenomenon was related to the changes in the calcium-to-phosphorous ratio, resulting in a reduction of carbonate and pyrophosphate formation [12,40]. It was also reported that remineralization spaces acting like free-ion traps occurred with laser etching [22]. However, despite these advantages and because of the low bond strength reported in many studies [12,16,18,21,32], laser-etching applications should be improved. In addition, larger samples by means of SEM should be examined in future bond strength studies.

Laser irradiation, a fissurotomy-bur, and Cojet-Prep did not eliminate the need for acid-etching of enamel prior to the placement of a fissure sealant. 2W (20Hz or 40 Hz) laser irradiation alone may be an alternative to conventional enamel acid-etching.

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