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Effect of Er: YAG Laser Enamel-etching and Sandblasting on the Bond Strength of Fixed Lingual Retainers

Mahdjoube Goldani Moghadam[1], Hanieh Kazemi[2*], Mohadese Bani Asadi[3]

[1]Assistant Professor of Orthodontics, Faculty of Dentistry, Department of Orthodontics, Faculty of Dentistry, Birjand University of Medical Sciences, Birjand, Iran
[2]Post Graduate Student, Department of Orthodontics, School of Dentistry, Mashhad University of Medical Sciences, Mashhad, Iran
[3]Post Graduate Student, Department of Endodontics, School of Dentistry, Mashhad University of Medical Sciences, Mashhad, Iran

***Corresponding author:** Hanieh Kazemi, Post graduate student, Department of Orthodontics, School of Dentistry, Mashhad University of Medical Sciences, Vakil Abad Blvd, Mashhad, Iran

Email: haniyekazemi71@gmail.com

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Abstract

Aim: This study aims to compare the shear bond strength (SBS) of different combinations of retainer wires and enamel preparation methods.
Methods: A total of 180 extracted mandibular bovine incisors were randomly divided into nine groups of 20 paired teeth each. Three techniques were employed to prepare the enamel: acid etches only, Er:YAG laser before acid etch, and sandblast before acid etch. The retainer wires, including Bond-A-Braid, GAC Wildcat Twistflex Wire, and TruForce coaxial wire, were bonded with the adhesive Transbond LR and SBS values were measured. The two-way ANOVA test was used to evaluate the effect of the conditioning method in combination with the retainer wire type and the interaction of two variables. Pairwise comparisons were done using the Tukey post hoc test. A value of $P \leq 0.05$ was considered to be significant for all statistical tests.
Results: The highest shear bond strength value was found for sandblasted surface bonded with Bond-A-Braid wire. The combination of acid-etched enamel/GAC Wildcat Twistflex wire revealed the lowest value of the SBS. Statistically significant differences did not exist for the Adhesive Remnant Index (ARI) scores among the study groups.
Conclusion: Sandblasting and laser irradiation before the acid etching significantly increased the SBS. Differences in the SBS values of different wires were insignificant.

Keywords: Er:YAG Laser, Retainer, Sandblasting, Wire.

1. Background

Since the introduction of lasers to dentistry in 1989, laser application has become increasingly prevalent and is eventually replacing the conventional methods in many aspects. Dental literature is faced with more topics related to laser technology every day (1). Gingival re-contouring, exposure of unerupted teeth, frenectomies, excessive and inflamed tissue removal, and photostimulation of aphthous and herpetic lesions are examples of laser application on soft tissues in orthodontics (1) Laser technology has been widely used on hard tissues for different purposes in orthodontics, including prevention of enamel demineralization (2,3), laser etching of bonding surfaces such as intact enamel (4–6), fluorosed enamel (7) , hypomineralized enamel (8), bleached enamel (9), porcelain (10–12) and surface cleanup after debonding (13), and laser debonding and re-conditioning of ceramic brackets (14–18).

An important and sometimes challenging part of each orthodontic treatment is the retention of therapeutic outcomes, which is highly dependent on the appropriate retention protocols. These days, the choice of orthodontic treatment by adults is increasing and this itself adds to our challenges in counteracting relapse tendencies since it is difficult to persuade adults to wear removable retention appliances. Fixed lingual retainers are completely invisible from the front, less dependent on patient cooperation, and provide long-term and sometimes permanent retention, therefore, they are increasingly used these days (19). Flexible spiral wire retainer is a frequently used type of fixed retainer, made up of thin wires (0.015–0.0215 inches), and bonds all the teeth in the intended region. Despite the long-term results, which indicate that the flexible spiral retainer provides reliable and useful retention (19), the possibility of bond failure always exists and causes frustration for orthodontists and enamel damage following repeated bonding (20). Thus, every effort should be made to ensure reliable bonding and the long-term stability of the treatment results.

While the literature is rich with studies on the conditioning of surfaces for bracket bonding, to the best of our knowledge, there were surprisingly fewer papers on the lingual surface preparation for bonding fixed orthodontic retainers (21, 22). Thus, this study aims to compare the effects of three different methods of lingual enamel conditioning (acid etching, sandblasting, and laser irradiation) on the shear bond strength of fixed lingual retainers that are made up of three different retainer wires.

2. Methods

A total of 180 freshly extracted mandibular bovine incisors, free of caries and intact in the structure, were selected for this study. All the procedures were performed by the same operator. The teeth were cleaned and immersed in 0.5% sodium hypochlorite for disinfection and stored in normal saline. All the teeth were examined under a dental unit lamp and all cracked teeth were excluded.

Teeth grouping

The teeth were randomly divided into nine groups of 20 pairs each. Bovine incisors with similar dimensions were selected in pairs and each pair was embedded in a block of acrylic resin up to the cervical region of the teeth in a manner that the retainer wire could be placed parallel to the crown. Test groups were as follows:

Group 1: Only acid etching/retainer wire: Bond-A-Braid

Group 2: Only acid etching/retainer wire: TruForce coaxial wire

Group 3: Only acid etching/retainer wire: GAC Wildcat Twistflex wire

Group 4: Lased before acid etching/retainer wire: Bond-A-Braid

Group 5: Lased before acid etching/retainer wire: TruForce coaxial wire

Group 6: Lased before acid etching/retainer wire: GAC Wildcat Twistflex wire

Group 7: Sandblasted before acid etching/retainer wire: Bond-A-Braid

Group 8: Sandblasted before acid etching/retainer wire: TruForce coaxial wire

Group 9: Sandblasted before acid etching/retainer wire: GAC Wildcat Twistflex wire.

Enamel conditioning

In the first three groups, the enamel surface of the teeth was etched using 37% phosphoric acid (Fine Etch, Korea) for 30 seconds and then rinsed and dried with oil and moisture-free air.

Laser groups (3, 4, and 5) were initially irradiated with the Er:YAG laser (KEY Laser 3+, KaVo Dental Corporation, Biberach, Germany). The average power output was 1.28 W and the irradiation was done at 120 mJ and 18 Hz for 15 seconds. Lasing of the enamel was done at pulse mode, using a 2060 handpiece (KaVo Dental Corporation, Biberach, Germany) perpendicularly held at a distance of 10 mm, from the teeth. The system was equipped with air and water cooling spray. Following the laser irradiation, the enamel surfaces were rinsed, dried, and etched with 37% phosphoric acid similar to the first three groups.

In groups 7 to 9, the teeth were initially sandblasted (KaVo PROPHYflex®, KaVo Dental GmbH, Biberach an der Riss, Germany) with 50 µm aluminum oxide particles at 75 psi for 4 seconds operating ata distance of 10 mm.

Following the enamel preparation, a thin layer of unfilled resin (Transbond™ XT primer, 3M Unitek AG, Monrovia, CA, USA) was applied to the enamel and left uncured.

Retainer wires

Three different, frequently used retainer wires were used in this study, as follows:

- Bond-A-Braid (Reliance Orthodontic Products Inc., Itasca, USA), a 0.016×0.022 inch dead-soft eight-braided wire,
- GAC Wildcat Twistflex wire (Ortho Care Ltd., Bradford, UK), a three-strand twisted 0.0195 inch stainless steel wire,
- TruForce coaxial wire (Ortho Technology, Pet Lane, United States), a six-stranded 0.0175 inch stainless steel wire.

Bonding fixed lingual retainer

The direct bonding procedure was followed for the retainer. To create a standard condition, a 15 mm wire was used in each group. The selected wire was held in position and tacked to the teeth with a small amount of flowable light-cured composite resin (Tetric EvoFlow™, Ivoclar Vivadent GmbH, Ellwangen, Germany) and was cured for five seconds using a light-emitting diode (Curing, Morita, Japan). This initial tacking prevents wire displacement during the addition of the composite bulk. Then the adhesive bulk of Transbond LR (3M Unitek AG, Monrovia, CA, USA) was added and contoured from the gingival margin to the incisal edge and was cured for 20 seconds.

Shear bond strength testing

Following the bonding of retainer wires, the specimens were thermocycled in water between 5°C and 55°C for 500 cycles (30 seconds in 5°C water and 30 seconds in 55°C water). The shear bonding strength (SBS) was measured using the universal testing machine (Instron 5965, Instron, Pfungstadt, Germany). The line of force application was directed along the occlusal-apical axis of the incisors to resemble the bite force. The SBS was measured by the crosshead speed of 1 mm/min while the edge of the machine rod was held in the middle of the paired segment (between two teeth). The force required to achieve bond failure was recorded in Newtons. Data can be converted to mega-Pascal by dividing the value of force by the bonding base area, which was nearly 12 square millimeters (to provide a standardized bonding procedure, an area of 4 mm in width and 3 mm in height on each tooth was considered to serve as bonding surface).

Scanning electron microscope examination

Following the enamel conditioning and before the bonding of the retainer wire, one specimen (three samples totally) from each group were selected and inspected under a scanning electron microscope (SEM, VEGA, TSCAN) at 200x magnification and a voltage of 15 kW (Fig. 1, 2, and 3).

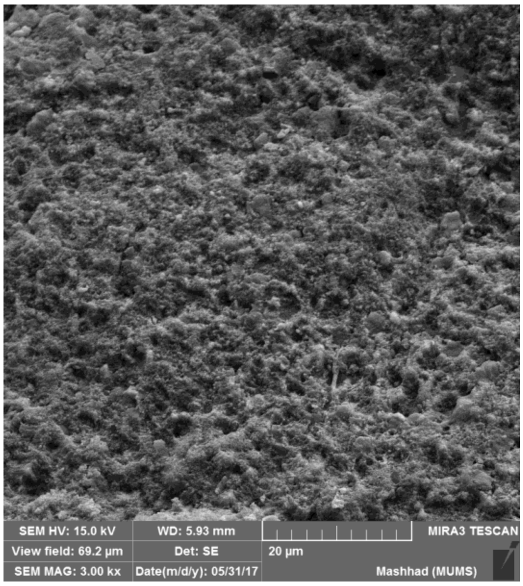


Figure 1. Scanning electron microscopic image of the laser group

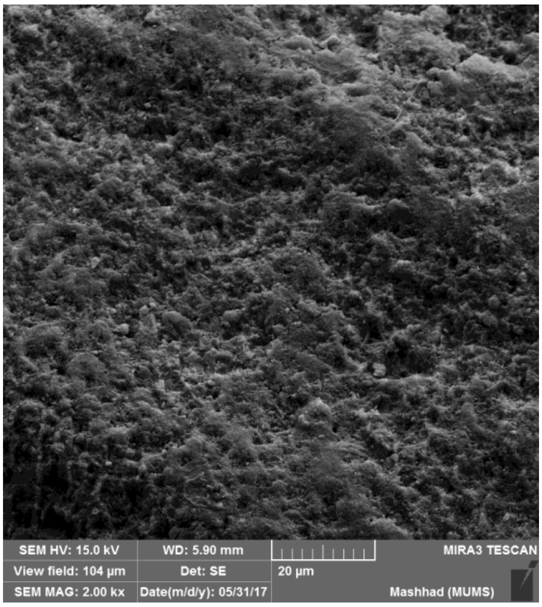


Figure 2. Scanning electron microscopic image of the sandblasting group

Adhesive remnant index

After debonding, the enamel surface of each tooth (total of 180 teeth) was examined under a stereomicroscope at 10x magnification to evaluate the amount of residual resin and the mode of failure. The Adhesive Remnant Index of Oliver (23) was used to report the result, which is as follows:

Score 1: All adhesive remained on the enamel surface

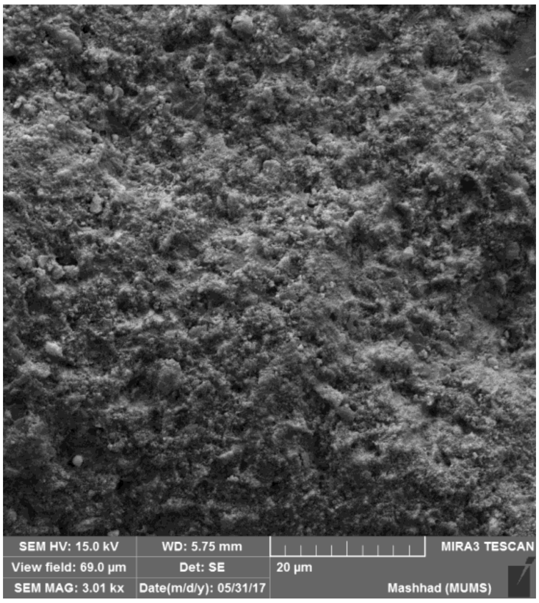


Figure 3. Scanning electron microscopic image of the only acid etching group

Score 2: More than 90% of the adhesive remained on the enamel surface

Score 3: Between 10% and 90% of the adhesive remained on the enamel surface

Score 4: Less than 10% of the adhesive remained on the enamel surface

Score 5: No adhesive remained on the enamel surface.

Statistical analysis

Descriptive statistics, including the means and standard deviations of the SBS, were calculated using the SPSS software (IBM, Ehningen, Germany). The Kolmogorov–Smirnov test showed a normal distribution of data (P≤0.05). The two-way ANOVA was used to evaluate the effect of the conditioning method in combination with the retainer wire type. Pairwise comparisons were done using the Tukey post hoc test. A value of P≤0.05 was considered to be significant for all statistical tests.

3. Results

As presented in Table 1, the highest shear bonding strength value was found for the sandblasted surface bonded with Bond-A-Braid wire (M = 162.79 N; SD = 13.38 N), followed by the combination of lased enamel/Bond-A-Braid wire, and sandblasted enamel/TruForce coaxial wire in decreasing order. The combination of acid-etched enamel/GAC Wildcat Twistflex wire had the lowest SBS value.

The results of the two-way ANOVA revealed significant differences in shear bond strength values among the various retainer wire/enamel conditioning method combinations. The enamel conditioning method used for the preparation of the teeth for bonding retainer wires showed significant effects on the measured SBS values (P<0.001) while no significant differences in the SBS values were found among the three retainer wires (P = 0.067).

A two-way ANOVA test was done to examine and investigate the relationship between the type of retainer wire and the surface preparation method (Table 2). Based on the results, no statistically significant effect on SBS (P = 0.636) was found between the retainer wire and the preparation method. The type of retainer wire was also found to not significantly influence the amount of SBS (P = 0.07), although the surface preparation method was found to have a significant effect on SBS (P<0.001). In Plot 1, due to the lines not intersecting, no relationship was found between the type of wire and the method of surface preparation.

The results of the Tukey post hoc test showed that when measuring the SBS, the lingual enamel

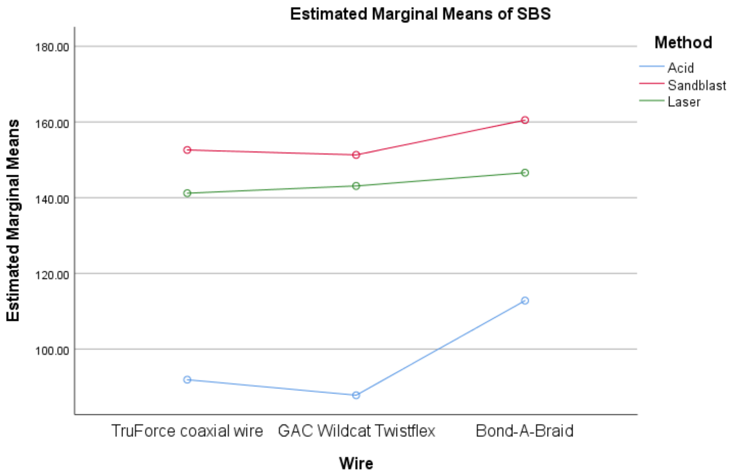
Table 1. Descriptive statistics including mean and standard deviations (SD) of SBS values among the study groups. (MPa)

Wire	Method	Mean	SD	Std. Error	95% Confidence Interval	
					Lower Bound	Upper Bound
TruForce coaxial wire	Acid	94.085	22.12816	5.367	83.414	104.756
	Sandblast	151.385	19.40332	5.367	140.714	162.056
	Laser	140.213	19.55066	5.367	129.542	150.884
GAC Wildcat Twistflex	Acid	92.924	34.78761	5.367	82.253	103.595
	Sandblast	150.224	10.81203	5.367	139.553	160.895
	Laser	139.052	23.08174	5.367	128.381	149.723
Bond-A-Braid	Acid	105.491	32.74752	5.367	94.820	116.162
	Sandblast	162.791	13.38532	5.367	152.120	173.462
	Laser	151.618	19.67062	5.367	140.948	162.289

Table 2. The results of the interaction of two variables (preparation method and retainer wire) on the SBS values, using the two-way ANOVA test.

Dependent Variable: SBS					
Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Corrected Model	59600.823a	8	7450.103	14.126	0.0001
Intercept	1567587.172	1	1567587.172	2972.219	0.0001
Wire	2893.583	2	1446.791	2.743	0.070
Method	55358.727	2	27679.363	52.481	0.0001
Wire * Method	1348.513	4	337.128	0.639	0.636
Error	42720.454	81	527.413		
Total	1669908.449	90			
Corrected Total	102321.277	89			

a. R Squared = 0.582 (Adjusted R Squared = 0.541)



Plot 1. The profile plot showing the interaction of two variables (preparation method and retainer wire) on the SBS values.

surfaces that were conditioned with sandblasting or laser irradiation before etching, revealed significantly higher values compared to only acid-etched teeth. However, there was no significant difference between laser irradiation and sandblasting concerning the SBS value of the fixed retainer wire (P>0.05) (Table 3). The enamel surfaces that were conditioned by the means of sandblasting or laser irradiation before the acid etching yielded higher mean values of the SBS by 158% and 147%, respectively.

Frequencies of the adhesive remnant index (ARI) scores for the study groups are presented in Table 4. No statistically significant difference was found regarding the ARI among the study groups. However, most of the teeth (nearly 70%) scored 2 and 3 on the ARI scores which meant that more than 10% of the adhesive remained on the enamel surface.

Table 3. The results of Multiple Comparisons using the Tukey HSD post hoc test.

(I) Method	**(J) Method**	**Mean Difference (I-J)**	**Std. Error**	**Sig.**	**95% Confidence Interval**	
					Lower Bound	**Upper Bound**
Acid	Sandblast	-57.3000*	5.87911	0.0001	-71.3243	-43.2757
	Laser	-46.1277*	5.87911	0.0001	-60.1520	-32.1033
Sandblast	Acid	57.3000*	5.87911	0.0001	43.2757	71.3243
	Laser	11.1723	5.87911	0.145	-2.8520	25.1967
Laser	Acid	46.1277*	5.87911	0.0001	32.1033	60.1520
	Sandblast	-11.1723	5.87911	0.145	-25.1967	2.8520

* The mean difference is significant at the 0.05 level.

Table 4. Distribution of ARI scores.

Wire	**Method**	**Score 1**	**Score 2**	**Score 3**	**Score 4**	**Score 5**
TruForce coaxial wire	Acid	10%	10%	0	0	0
GAC Wildcat Twistflex	Acid	0	6%	14%	0	0
Bond-A-Braid	Acid	0	2%	6%	6%	6%

TruForce coaxial wire	Sandblast	0	2%	10%	6%	2%
GAC Wildcat Twistflex	Sandblast	0	6%	4%	6%	4%
Bond-A-Braid	Sandblast	4	10%	0	4%	2%
TruForce coaxial wire	Laser	0	10%	10%	0	0
GAC Wildcat Twistflex	Laser	4%	12%	4%	0	0
Bond-A-Braid	Laser	0	12%	8%	0	0

4. Discussion

Retention is an important and sometimes challenging part of any orthodontic treatment. Fixed lingual retainers should be considered a useful and advantageous mode of retention since they are tolerated well by patients, especially adults because they are less dependent on patient cooperation (19). Furthermore, fixed retainers are especially indicated in cases of median diastemas, spaced dentition, single mandibular incisor extraction to prevent space reopening, and to hold severely rotated or palatally impacted teeth in post orthodontic positions (19). The establishment of a post-treatment physiological equilibrium is possible while the fixed lingual retainers are in place, which is evident based on the frequently observed event of space opening distal to the terminal ends of the retainer in the first six months following retainer placement (19).

In any procedure based on bonding techniques, bond failure is a major concern among clinicians. It is an even more critical issue when fixed retainers are concerned since any failure in the retention protocol will lead to the loss of treatment results. The failure rate of the fixed lingual retainers in the form of bond failure or wire breakage has been reported in clinical studies to be in the range of 23% to 58% and 5% to 37% for maxillary and mandibular retainers, respectively (24–28). Failure of the lingual fixed retainer and the subsequent need for a rebonding procedure compromises the treatment results, frustrates the orthodontist and the patients, and also increases the risk of enamel fractures (20). Therefore, all attempts should be made to obtain bond strength values as high as possible. In this regard, bonding agents, lingual wire properties, including the type of material and dimensions, and the enamel conditioning methods, play important roles. In this study, we compared the three methods of enamel conditioning, combined with three different wires to compare the shear bond strengths of the fixed retainer wires. To the best of our knowledge, very few studies have evaluated and compared the preparation methods of the lingual enamel for bonding fixed retainers.

To measure the SBS of the fixed retainers, the bovine incisor teeth of the patients in each group were bonded with equal wire lengths of 15 mm. The bovine teeth were the appropriate choice here since it has been found that observing the bovine teeth yielded comparable results to the human teeth and analyzing the incisors are to be preferred to the premolars and the molars when studying the SBS (29, 30). Force was applied to the interdental section of the wire in each paired incisor using the Instron testing machine. Since the SBS values depend on both the direction and location of the applied force, we used a vertical force on the interdental segment, which is the most fragile part of the retainer wire, to measure the lowest SBS value (27, 31, 32). This also enabled us to compare our results of the SBS values to those of others (21, 33).

The sandblasting technique has been used for different purposes in orthodontics, including removing residual resin from the debonded bracket base for recycling and the enamel (34), preparing the amalgam surface for bracket bonding (35), and sandblasting the ends of 3-3 mandibular retainers (36). In this study, we evaluated the effect of sandblasting on the enamel surface of the SBS value of the fixed retainer wire before acid etching. The results showed a significant increase in the mean SBS value of the pre-sandblasted samples, which was 158% higher compared to the groups that went through only acid etching. This finding is consistent with that of Reicheneder et al., who reported that sandblasting of dental bonding surfaces caused a 217% increase in the mean SBS value of the patients (21). This observation can be explained by the fact that sandblasting removes plaque and derbies, yielding a clean bonding surface. It also increases the micro-retention and roughness of the enamel, resulting in greater SBS values. However, this procedure cannot be an alternative to acid etching (37).

The results showed that the SBS value of the lased samples increased significantly compared to the groups that only experienced acid etching but it was comparable to sandblasted samples. The SEM images seem to confirm this finding since the enamel etching patterns of the sandblasted and lased enamel resembled each other. This finding is consistent with that of Kiryk et al., who reported that the shear bond strength of orthodontic brackets with the Er:YAG laser combined with conventional etching with 37% acid phosphoric was higher than with the conventional etching only (38). In contrast, Biyiklioglu et al. recorded a statistically significant difference in SBS of fixed lingual retainers, between the etching methods. Higher SBS values were observed in the acid etching group (2.33 ± 0.55 MPa) versus the Er:YAG laser group (1.28 ± 0.86 MPa) (39). An older study performed by Karaksi et al. showed that the laser was a successful tool for enamel etching and the results for both the groups (acid etching and laser etching) were satisfactory (22). Although sandblasting caused a larger increase in the mean SBS value compared to that caused by lasing, the difference was insignificant. This also accords with our earlier observation on the comparison of these two methods for resin removal from the debonded bracket base and their effects on the shear rebond strengths of recycled brackets (40).

We used three different retainer wires in this study. The combination of the sandblasted surface/Bond-A-Braid wire had the highest SBS value and the acid-etched enamel/GAC Wildcat Twistflex wire produced the lowest. The results of the statistical analysis showed that the differences among the SBS values, based on the type of retainer wire, were insignificant, which is also corroborated by previous studies. Reicheneder et al. found that the increased strand count of the retainer wire has an overall positive effect on its clinical performance; however, it is overshadowed by other factors such as the influence of the bonding system on the SBS values (21). Aldrees et al. compared the initial bond strength of different wire-and-composite combinations and found a greater SBS value for the coaxial wire (PentaOne) compared to the solid chain retainer (27). Therefore, it can be concluded that the diameter of the retainer wire or its winding affects the SBS value. Baysal et al. compared three different orthodontic wires (0.0215 inch five-stranded wires; PentaOne, Masel), one 0.016×0.022-inch dead-soft eight-braided wire (Bond-A-Braid, Reliance), and one 0.0195-inch dead-soft coaxial wire (Respond, Ormco) to fabricate the bonded lingual retainer (33). They evaluated the detachment force, the amount of deformation, fracture mode, and pull-out force of these wires. The results showed that the detachment force and fracture mode were similar for the groups but the dead soft wires had a greater deformation (33). The Bond-A-Braid wire, used in this study, is a dead-soft eight-braided wire, which the manufacturer claims to be superior to round braided wires in case of torque control and patient comfort because of the flattened wire profile (33). This wire has been used in previous studies done on fixed retainers, enabling us to compare our results to those of other researchers (21, 33). Moreover, different wire dimensions for the fabrication of lingual retainers have been recommended in the literature and the different retainer wires such as the 0.0215 inch multi-stranded wire (41), 0.0195 to 0.0215 inch wire (25), five-stranded wire instead of thinner wire (19), and 0.015 to 0.0215 inch multi-stranded wire (19) are recommended. However, there is no consensus among experts regarding the most clinically suitable lingual retainer wire.

Although the differences in the ARI scores were insignificant among the groups in this study, nearly 70% of the teeth had more than 10% of adhesive remaining on them. The present findings seem to be consistent with other studies that showed that the most common mode of failure was the bond failure at the wire-composite interface (41- 43). In our study, no statistically significant difference was found regarding the ARI among the study groups, but Biyiklioglu et al. reported that more composites were retained on the enamel surface after the retainer was taken off in the acid group (39).

Since the normal range of forces in the oral cavity are within 3 to 18 N, bonding surfaces should at least resist forces of 6 to 8 N. Thus, all the preparation methods and retainer wires used in this study possess sufficient SBS value for the orthodontic application. There are few reports in the literature on the long-term clinical performance of bonded retainers.

In the in vivo conditions, the total failure rates of bonded retainers range from 10.3% 41 to 47.0%. In the maxilla, the failure rate for retainers is 48% to 50%, and a 15% to 20% failure rate for individual attachments. In the mandible, the failure rate for retainers is 12% to 20%, and a 4.4% failure rate for individual attachments. These statistics could indicate the function of occlusal factors in the failure of such retainers, although an extensive range of observation periods can also influence the in vitro outcomes.

In in vivo conditions, the failure type usually seen is detachment at the wire/composite interface. Applying inadequate amounts of adhesive and material loss due to abrasion have been attributed to wire detachment from the surface of the composite. Furthermore, abrasion of mandibular retainers has been linked to mechanical forces such as tooth brushing and chewing (41).

Conclusion

Sandblasting and Er:YAG laser irradiation prior to acid etching significantly increases the SBS value of fixed lingual retainers.

Sandblasting and Er:YAG laser irradiation yield comparable results regarding the SBS values.

Bond-A-Braid, GAC Wildcat Twistflex, and TruForce coaxial wires yield similar SBS values.

All the tested combinations revealed sufficient SBS values for clinical applications.

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