ORIGINAL RESEARCH

Different Wire Surface Treatments on Adhesion Efficacy of Orthodontic Fixed Retainer: An *In Vitro* Study

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Abstract

Aim: This study assesses the impact of surface treatment with sandblasting and Z-primer on the adhesion efficacy of fixed lingual retainers.

Materials and methods: Dead soft stainless steel wire 0.016 × 0.022-inch ($n = 120$) was treated by different techniques and classified into four groups equally ($n = 30$) according to surface treatment. Group I wire without treatment, group II wire treated with sandblasting, group III wire treated with Z-primer alone, and group IV wire treated with sandblasting with Z-primer. The stainless steel wire ($n = 40$) was bonded to 80 extracted premolars in pairs mounted in acrylic. Other stainless steel wires ($n = 80$) are embedded into acrylic blocks. All groups were divided into two subgroups according to thermocycling teeth samples were assessed by shear bond strength (SBS) A stereomicroscope was used to calculate the adhesive remnant index (ARI), while the acrylic block was by pull-out test. Finally, data were analyzed by IBM-SPSS (V 27, 2020). Mann–Whitney *U*-test; Kruskal–Wallis *H*-test and, two-way ANOVA were utilized to assess for SBS and pull-out.

Results: Kruskal–Wallis *H*-test showed a non-significant difference in ARI between all groups, while in two-way mixed ANOVA demonstrated a significant difference in SBS between group III (sandblasting/Z-primer) vs group I and group IV Z-primer ($p = 0.028$) and control ($p = 0.016$), and a significant difference between group II sandblasting vs both group I and group IV Z-primer ($p = 0.024$) and control ($p = 0.014$). The two-way mixed ANOVA tests showed a significant difference in pull-out between sandblasting/Z-primer vs Z-primer ($p = 0.012$).

Conclusion: Using of mixed surface treatment for fixed retainer as sandblasting with Z-primer is considered as the best method to increase adhesion efficacy between wire and composite and improve the quality of orthodontics fixation when compared with single treatment (sandblasting alone or Z prime). On the other hand, the sue of sandblasting alone for fixed retainer surface treatment is better than Z-primer alone but both treatments are better than fixed retainer without treatment.

Clinical application: Developed and examined new and traditional techniques used to treat the surface of wire used as a retainer after orthodontics treatment to improve patients' treatment and life quality and decrease the chance of relapse.

Keywords: Adhesive remnant index, Orthodontic retainer, Shear strength, Stereomicroscope.

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Introduction

Retainers are important for orthodontic treatment to succeed in the long term and prevent orthodontic relapse.[1] The posttreatment stability depends upon the sex, pathology of the surrounding tissue, patients' compliance, and retention procedure utilized. Orthodontic relapse can commonly occur even after a successful treatment. It was found that in 70–90% of the orthodontically-treated cases, various degrees of compensation in the lower dental arch occurred in the post-retention period, while the upper arch showed milder alterations.[2]

Retainers are generally divided into fixed and removable retainers, which are used to achieve stability. Removable retainers, there is less plaque and calculus accumulation and less gingival inflammation as compared with fixed retainers; however, they are less effective in relapse prevention due to the patient's cooperation. Indeed, fixed retainers are of choice for maintaining a long-term alignment of mandibular anterior teeth. They are easy and well-tolerated and do not cause tissue irritation unlike Hawley's retainer.[3]

A fixed retainer has a long survival time making it the choice for long-term retention.[1] Failure of a retainer might occur in the wire/composite interface, in the adhesive/enamel interface, or in the wire itself. Failure at the wire/composite interface is commonly related to composite[4] failure at the adhesive/enamel interface is mainly due to moisture or wire movement during bonding Butler and Dowling,[5] while failure related to the wire itself is due to stress-fracture and commonly occur with a small-diameter wire,[6] or due to service for a long time.[7]

Baysal and Uysal[8] reported that failure at the wire/composite interface is the most common failure pattern.

In dentistry, many mechanical and chemical surface treatments, such as milling, sandblasting, chemical application, and lasers

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improve the bond strength of the zirconia (Zir)/cement interface. One such technique sandblasting was found to increase mechanical retention and as a chemical method, multiple new zirconia primers have been developed.[9]

Sandblasting was recommended for lingual retainers before bonding to increase their bond strength. To maximize their retention, it was also recommended for enamel to be sandblasted before bonding retainers.[9] Recently developed zirconia primers have been introduced. However, examined the bond strength between orthodontic brackets and zirconia prostheses, and the effects of surface treatment with zirconia primers on bonding.[10]

Surface treatment with zirconia increases SBS as compared with no-primer and Z-primer application for bracket bonding to Zir prostheses.[10] Zir-based primer (Z-Prime Plus) contains a mixture of phosphate and carboxylate monomers that increase the bond strength of Zir to metals. Z-Prime Plus also increases the adhesion of self-adhesive resin cement to air-abraded zirconia.

Studies have indicated that the sandblasting of brackets and orthodontic bands improves retention.[11,12] Sandblasting is applied to the metal surface by removing the smooth facial structure and increasing the surface area; thus improving the retention. Sandblasting with 60 nanometers of alumina for 3 seconds can achieve an effective bonding and is considered the best surface treatment. Millett et al.[13] demonstrated that the bond strength increased by 22% following sandblasting, whereas MacColl et al.[14] found that bond strength increased by 18–24% following sandblasting using a portable sandblasting machine for 5 seconds. Also, Zachrisson found that wire sandblasting increased the bond strength between it and the composite.[9]

Our study evaluated the efficacy of mechanical (Al_2O_3 sandblasting) and chemical (Z-Prime Plus) surface treatments to the fixed retainer to prevent relapse after exposure of specimens to thermal and mechanical cyclic loads to simulate mouth conditions. The null hypothesis was that surface treatment of fixed retainers via sandblasting and the application of Z-Prime Plus can increase bond strength irrespective of the type of luting cement.

Materials and Methods

Our study was approved by the Research Ethics Committee of the Faculty of Dentistry, Mansoura University under code no. (A0303023OR). This study was done in 2023 for 6 months.

Sample Size Calculation

The sample size was performed according to the previous study[15] by using the Power Analysis and Sample Size (PASS) program (version 15, 2017). NCSS, LLC. Kaysville, Utah, US. A factorial design with two factors (A and B) at four levels for factor A (wire surface treatment) and two levels for factor B (thermocycling), that is, eight cells (treatment combinations). Eighty wires were needed to provide 10 wires per cell. This achieved 84% power when an F test was utilized to test factor A at a 5% significance level and a large effect size ($f = 0.400$), gained 94% power when an F test was used to test factor B at a 5% significance level and a large effect size ($f = 0.400$), and achieved 84% power when an F test is utilized to test the $A*B$ interaction at a 5% significance level and a large effect size ($f = 0.400$). Similarly, the same hypothesis and sample size will be applied when conducting the study on teeth. 80 premolar teeth are required to provide 10 teeth per cell. The total sample size for both teeth and block is 120 wires.

Specimens' Preparation and Study Design

Dead soft stainless steel 16 × 22-inch wire specimens were classified according to the method of surface treatment into four groups equally ($n = 30$) as group I (control group): without any treatment, group II wires were treated with sandblasting only, group III: wires were treated with Z-primer only, and finally group IV: wires were treated with sandblasting and Z-primer.

Eighty wires were fixed with block samples according to treatment ($n = 20$) also for teeth sample 40 wires were fixed in 80 teeth as paired according to each group ($n = 10$). All groups were divided into two subgroups subgroup a 2,500 and subgroup b 5,000 cycles according to the thermocycling process (Fig. 1).

Surface Treatments

Sandblasting: SS wires underwent air abrasion for 10 seconds at a 10 mm distance using Al_2O_3 50 µm particles at 0.35 MPa.[16]

Z-Prime Plus

The cleaning of wires was done under running water, rinsed with 40% ethanol, and dried then 1 coat of Z-Prime Plus (Bisco Inc, Schaumburg, IL, US) was applied and cured for 20 seconds.

Testing

Pull-out Test

Eighty cylindrical acrylic blocks (25 mm in diameter and 10 mm high) were prepared with central hole (3 × 2 mm). The holes approximated the dimensions of the composite utilized for lingual retainers. A total of 20 blocks were assigned to each group. All holes were filled with composite Transbond XT (M Unitek, Monrovia, CA, USA) and one of the free ends of a 10 cm section of the wire was embedded in the composite. The adhesive was cured for 40 seconds. Samples were preserved in distilled water (DW) for 24 hours before thermocycling. All groups were divided into two subgroups based on the thermocycling process to 2,500 ($n = 10$) and 5,000 ($n = 10$) cycles. Aging was performed by Mechatronik Thermocycler (SD Mechatronik Thermocycler, Julabo GmbH, FT 200, Seelbach, Germany) with H_2O at 5°C and 55°C for 2,500 and 5,000 cycles, with a dwell duration of 20 seconds and a 5 seconds transfer time between baths, to simulate adhesive aging in the mouth for 3 months and 6 months, respectively.[17]

The acrylic block was secured with a stainless steel alignment jig and a hole through the block (Fig. 2). The instron testing machine (ITM) (Instron Corp., Norwood, MA, US) was placed in tensile mode with a controlled speed of 10 mm/minute. Blocks were loaded into the ITM and forces were applied along the long axis of wires.[15] The force that detached the wire from the composite was recorded.

Shear Bond Strength

Teeth Preparation and Bonding

This experiment used 80 premolar teeth extracted due to orthodontic or periodontal causes. They were collected from patients attending outpatient clinics of the Oral and Maxillofacial Surgery Department (Mansoura University). Inclusion criteria included intact lingual surface without caries or microcracks, no white spots, dental fillings, or hypoplasia, no past exposure to chemical agents, for example, bleaching material, and no previous bracket bonding. After extraction, all teeth underwent cleaning and each two premolars was embedded in acrylic blocks (Fig. 3) and then kept in DW at 37°C to prevent dehydration. At the beginning

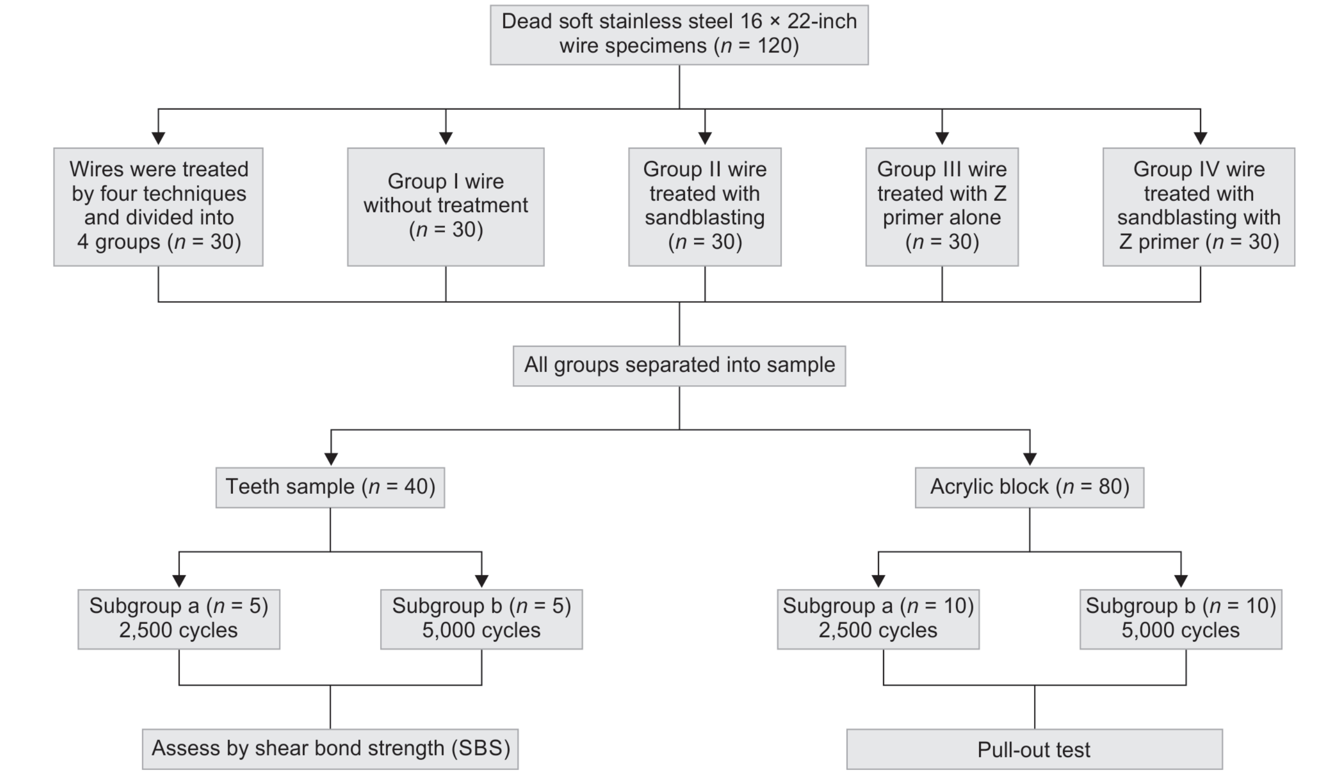

Fig. 1: Represented study design

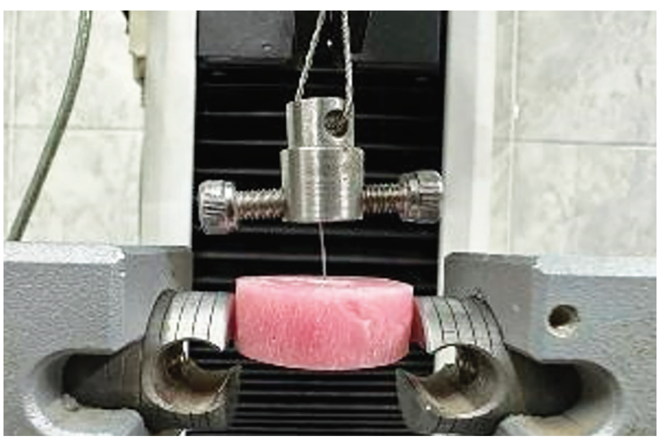

Fig. 2: Tensile strength test for wires embedded in acrylic groups pull out test

Fig. 3: Mounted samples

of the experimental work, all teeth underwent pumicing and were rinsed in water.[18]

The lingual surfaces were pumiced with fluoride-free pumice for 10 seconds, rinsed in water for 10 seconds, and air-dried for 5 seconds. The lingual surfaces were cleaned and thoroughly rinsed and air-dried for 20 seconds, etched with 37% phosphoric acid for 30 seconds (Scotch bond universal etchant), the surface then had a chalky white appearance after being dried. Transbond XT primer (M Unitek, Monrovia, CA, USA) was applied on the etched surfaces and cured for 40 seconds.

A test wire ($n = 40$) 10 mm in length was cut and its midpoint was marked using a pencil, then placed on the primed surface of the tooth according to the treatment technique. The wire was placed parallel to the mold base and below the point of contact between the teeth in the mold. A wire bonder tip was used to apply the composite which was then cured for 10 seconds using an light emitting diodes curing unit (LED) curing unit (light intensity = 400 mw/cm) which was placed as close as possible to the tooth surface. Each composite bulk had a diameter of 4 mm and a depth of 1.5 mm. Following light curing, teeth were kept in DW for 24 hours.

All groups were divided into two subgroups based on the thermocycling process to 2,500 ($n = 5$) and 5,000 ($n = 5$) cycles. Aging was performed by Mechatronik Thermocycler (SD Mechatronik Thermocycler, Julabo GmbH, FT 200, Seelbach, Germany) with H_2O at 5°C and 55°C for 2,500 and 5,000 cycles, with a

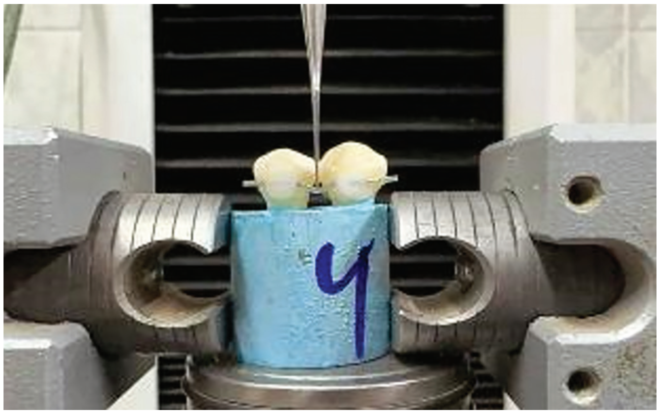

Fig. 4: Experimental design for testing the SBS

dwell duration of 20 seconds and a 5-second transfer time between baths to simulate adhesive aging in the mouth for 3 months and 6 months, respectively.

Debonding

Embedded specimens were fitted in a jig attached to the base plate of the ITM to evaluate SBS (Fig. 4). A chisel-edge plunger was mounted in the mobile crosshead of the ITM and was positioned so that it was aimed at the marked midpoint of the test wire. The chisel edge was cautiously positioned to avoid contact with the specimen. The crosshead speed was set at 1 mm/minute and the force that caused debonding was recorded.[19]

Adhesive Remnant Index

The enamel surface was examined under SEM (Joel, JSM-6510 LV, Tokyo, Japan). Using the ARI proposed by Artun and Bergland,[20] three blinded examiners scored the amount of adhesive remnants post-debonding. The scoring system includes four categories:

- Score 0 = no adhesive left on the tooth.
- Score I = less than half of the adhesive left on the tooth.
- Score II = more than half of the adhesive left on the tooth.
- Score III = all adhesives left on the tooth.

Statistical Analysis

Data were analyzed by IBM-SPSS (V 27, 2020). Mann–Whitney *U*-test was utilized to compare ARI between the two thermocycling types in each group while Kruskal–Wallis *H*-test was utilized to compare ARI between the four groups in each thermocycling type. Two-way ANOVA was utilized to assess the group *Thermocycling interaction effect on SBS and pull-out. For insignificant interaction effects, the main effect of group and thermocycling were reported followed by pairwise comparisons whenever required.

Results

Pull-out Test

Table 1 presents the mean values of the pull-put test intra-groups under investigation. The estimated mean (Standard error) was 81.03 (2.87), 84.44 (2.87), 78.66 (2.87), and 91.62 (2.87) for control, sandblasting, Z-primer, and sandblasting/Z-primer, respectively. There was a statistically significant difference ($F = 3.874$, $p = 0.013$, and partial eta squared = 0.139). Pairwise comparisons with Bonferroni adjustment for multiple tests revealed a statistically significant difference in pull-out between sandblasting/Z-primer vs Z-primer ($p = 0.012$), and marginally significant between sandblasting/Z-primer vs control ($p = 0.066$).

Table 1 depicts also no statistically significant interaction effect of the group by thermocycling on the load at maximum compressive load [N].

Table 1: Two-way mixed ANOVA pairwise comparisons of pull-out test intra-groups

Group	*Mean*	*SE*	*F*	*Sig.*	*Partial* η^2
Control	81.03	2.87	3.874	0.013	0.139
Sandblasting	84.44	2.87			
Z-primer	78.66[a]	2.87			
Sandblasting/Z-primer	91.62	2.87			

SE, standard error; Sig., significance (*p*-value). Partial eta squared is a measure of effect size. [a]Significant between Sandblasting/Z-primer vs Z-primer

Table 2: Two-way-mixed ANOVA pairwise comparisons of SBS test between four groups

Group	*Mean*	*SE*	*F*	*Sig.*	*Partial* η^2
Control	81.3	3.39	6.724	0.001	0.379
Sandblasting	96.90	3.39			
Z-primer	82.3	3.25			
Sandblasting/Z-primer	96.6	3.39			

SE, standard error; Sig., significance (*p*-value); Partial eta squared is a measure of effect size

Shear Bond Strength

The estimated mean intra-groups (Standard error) was 81.03 (3.39), 96.90 (3.39), 82.36 (3.25), and 96.63 (3.39) for control, sandblasting, Z-primer, and sandblasting/Z-primer, respectively. There was a statistically significant difference ($F = 6.724$, $p = 0.001$, and partial eta squared = 0.379). Pairwise comparisons with Bonferroni adjustment for multiple tests revealed a statistically significant difference in SBS between sandblasting/Z-primer vs both Z-primer ($p = 0.028$) and control ($p = 0.016$), and a statistically significant difference between sandblasting vs both Z-primer ($p = 0.024$) and control ($p = 0.014$).

Also, Table 2 presents no statistically significant interaction effect of the group by thermocycling on the SBS.

Adhesive Remnant Index

All studied groups scanned under SEM are given in Table 3. The Kruskal–Wallis *H*-test showed no significant difference in ARI intra and inter-groups of thermocycling.

Discussion

Several methods have been found to enhance the stability of corrections following orthodontic treatment. Maintaining the long-term stability after treatment is a major challenge for the orthodontist.[21] Posttreatment stability is affected basically by four sources of changes, such as continuous reorganization of dental tissues, physiologic movement of teeth, muscular imbalance because of the new potentially unstable condition, presence of inherent dental factors like tooth morphology and agenesis as well as continuous facial growth posttreatment.[22]

Table 3: Kruskal–Wallis *H*-test ARI intra-groups and inter-groups with different thermocycling.

	Thermocycling						
	2,500			*5,000*			
Group	*Median*	*Minimum*	*Maximum*	*Median*	*Minimum*	*Maximum*	*P1*
Control	2	0	3	2	0	3	1.00
Sandblasting	1	0	2	1	0	3 3	0.690
Z-primer	2	0	3	2	0	2 3	1.00
Sandblasting/Z-primer	0	0	1	1	0	2 2	0.548
P2		0.155			0.417		

P1, comparisons between the two thermocycling intra-groups (Mann–Whitney *U* test); P2, comparisons between the inter-groups in each of the two thermocycling (Kruskal–Wallis *H* test)

Fixed retainers are the most frequently utilized in the orthodontic retention phase. They have better aesthetics, do not require patient cooperation, are effective, and are suitable for life-long retention. Nonetheless, fixed requirements have many drawbacks since they require a particular bonding technique, are fragile, and have a tendency to cause periodontal problems due to weak oral hygiene.[23]

The orthodontic wire is utilized as a retainer attached to the lingual surfaces of maxillary and mandibular teeth. Failure of retainers varies from simple wire separation from a tooth to its complete deboning from teeth. Failure at the wire/composite interface is mostly related to composite, failure at the adhesive/enamel interface is mainly due to moisture contamination or wire movement while bonding, while failure related to the wire itself is due to stress-fracture and is commonly attributed to small-diameter wires, and service for a long time.[5]

In the mouth, lingual retainers are exposed to several stresses because of masticatory force, occlusion, and para-functional habits. Repeated subcritical loading causes fatigue resulting in complete or partial fracture of the retainer complex. Thermocycling and cyclic loading are common *in vitro* tests that are performed to simulate the intra-oral loads.[24]

In this study, we compare the traditional method with a novel Z-primer which was used 1st time in the treatment of stainless steel wire and we try to improve the efficacy of this technique to increase the quality of the retainer and prevent orthodontics relapse.

No significant difference in thermocycling was shown among all studied groups regarding pull-out (82.23) and shear bond strength (SBS) test (86.10) and this result agreed with Golshah and Amiri Simkooei,[24] who did not find a significant difference in thermocycling on SBS (55.57).may due to the samples treated with thermocycling (10,000 cycles) In contrast, Aksakalli et al.[25] reported that there was a negative effect of thermocycling on SBS and this result might be due to that the samples were treated under different thermocycling (50,000 cycles) and (10,000 cycles).

Continuous shear forces were applied on the wire interdentally at a controlled speed of 1 mm/minutes till specimen failure. This testing protocol was coincident with the testing protocol of Baysal et al.[15] and Aldrees et al.[26] Detachment forces were expressed in Newton as Pascal unit requires an even distribution of forces over the bonded surface area.

In our experiment, the SBS of wire-composite was increased by sandblasting which had the highest SBS and wire treated with sandblasting and Z-primer showed statistically greater SBS (96.3) than control specimens and the wires treated with Z-primer only. Such results agree with Oesterle et al.[27] who reported the highest bond strength of sandblasted wires (87.8). The strength of the bond proved to be much greater than the 300% increase in bond strength claimed by some authors while Kilinç and Sayar[9] had conflicted results as they found an insignificant difference in SBS between sandblasted and non-sandblasted wires. This disagreement might be because of that different braided wire size (0.010 × 0.028) was used.

In our study, the combined application of air abrasion and treatment with Z-primer enhanced the bond strength because of the increase in surface wettability by air abrasion and the increase in bond strength by the treatment with Z prime. Similarly, Zandparsa et al.[28] and Shin et al.[29] concluded that a combination of air abrasion and treatment with Z-Prime Plus enhanced the bond strength between Zir ceramic and resin cement because surface creating undercuts, which are important in forming micromechanical interlocking with the cement. However, Inokoshi et al.[30] found that SBS was decreased with the Z-Prime Plus probably because using of zirconia instead of a metal-bonded retainer.

Additionally, bond strength with Z-Prime Plus was lower than that with the sandblasting and sandblasting/Z-primer group. This might be due to carboxylic acid monomers present in Z-Prime Plus, which may weaken the adhesion between it and the methacrylate groups in resin cement. This was consistent with Lorenzoni et al.[31] who suggested that Z-primer has the lowest SBS without sandblasting because of weaknesses in the zirconia–resin cement bond interface); However, Al-Harbi et al.[32] demonstrated that primers that contained MDP, such as Z-Prime Plus had higher SBS values than those that did not have it. This can be attributed to the Z prime, which added an additional chemical bonding to the high mechanical bonding. MDP is composed of a hydrophilic phosphate terminal end that chemically bonds to Zir, and a polymerized methacrylate terminal end that bonds to resin.

The ARI score of 2 was predominant in control and Z-primer groups while a score of 1 was predominant in sandblasting and sandblasting/Z-primer groups (5,000) and a score of 0 in sandblasting/Z-primer groups (2,500). The sandblasting and sandblasting/Z-primer groups showed an ARI score of 1 and a score of 0, respectively. Our results agree with other reports in which a direct relationship was found between bond strength and ARI score. This suggests that higher bond strength has an association with lower scores.[33]

Pull-out test was carried out to assess the micromechanical adhesion between the composite and the wire. Force was expressed in Newton (unit for force), rather than in Pascal (unit for pressure), as Pascal indicates that the used force was homogenously distributed across the surface area of the bond. During the pull-out test, forces of tension, shear, and torsion can simultaneously occur.[34]

The present study showed strong adhesion of the composite to the wire in a sandblasting group. This result agrees with Oesterle et al.[27] who concluded that the wire sandblasting resulted in the highest bond strength between it and the composite. This finding does not agree with Sonis[35] who reported an insignificant increase in bond strength after sandblasting orthodontic bracket bases. However, there was a significant difference in pull-out between sandblasting/Z-primer vs Z-primer, the same results were reported in another study by Shokry et al.[36] who said MDP-containing primer increased the retention strength of resin cement to the Zir crown after sandblasting. This disagrees with Pitta et al. [37] who reported a low bond strength of Z Prime Plus. It was found that the application of Z-Prime Plus decreased bond strength more than other MDP-containing primers, as carboxylic acid monomers might weaken the bond with the methacrylate groups of resin cement. Finally, according to the study result, we can advise clinicians to treat the lingual retainer with different methods to improve its quality and prevent relapse.

Limitations of this Study

It is an *in vitro* study in which we utilized the SBS test; such a test has the drawback of inhomogeneous stress distribution. Secondly, only thermocycling was utilized for the simulation of artificial aging to assess the durability, and stability of wire-composite adhesion. DW was used as artificial media, however, it differs from saliva in composition and potential of hydrogen (PH). Lastly, only one type of self-adhesive resin cement and one type of fixed retainer wire were used, so more studies are needed to evaluate other materials.

Conclusion

With the limitation and results of this study, we can conclude that using of mixed surface treatment for fixed retainer as sandblasting with Z-primer is considered as the best method to increase adhesion efficacy between wire and composite and improve the quality of orthodontics fixation when comparing with single treatment (sandblasting alone or Z prime). On the other hand, the use of sandblasting alone for fixed retainer surface treatment is better than Z-primer alone but both treatments are better than fixed retainers without treatment.

Data Availability

All data are included in the article.

Ethical Approval and Consent

This study was approved by the research ethics committee of the Faculty of Dentistry, Mansoura University (A0303023OR). All procedures performed have followed the relevant regulations and guidelines.

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