Shear bond strength of three different fixed retainers: Stainless steel wires versus fiber reinforced composite (An in Vitro study)

Anees Mahmood Mudhir[(1)]

Background and Objectives: Long term preservation of lingual retainer after active orthodontic treatment is mandatory in oral cavity to prevent teeth relapse to its original place before treatment which is documented in orthodontics and considered as a success factor of lingual bonded retainers. This in vitro study is conducted to evaluate and compare the bond strength (shear bond strength) of three different fixed lingual retainers using a specific retainer composite and fracture modes of different retainer's wire/adhesive combination.

Methods: One-hundred twenty extracted human upper premolar teeth (60 pairs) were divided into three groups(40 for each group) bonded with three different types of retainer wires (db Straight-8strand flattened nickel free braided wire 0.028 x 0.008 inches UK, 3M 0.0175; multi-stranded wire and Speed korean orthodontic fiber reinforced splint (2 mm x 200 mm - FS-2) which were bonded to the lingual surface of the teeth as fixed retainers by specific adhesives (Transbond LR, 3M). The specimens were debonded using a Universal Instron machine to measure shear bond strength. The site of failure was recorded for each specimen was calculated.

Statistical analyses were provided using one-way analysis of variance with inter-group comparison using the least significant difference.

Results: There was a statistically high significant difference among all three retainers groups ($p < 0.001$); db Straight-8 braid flat soft wire debonding force was (130±29.6N), followed by Speed fiber reinforced splint group (107.5±18.9 N), whereas the minimum was observed 3M Unitek coxial multi strand wire group(76±27.6 N).The site of failure was predominantly at the wire composite interface except in FRC was in enamel/composite interface.

Conclusion: db straight-8 wire delivered higher shear bond strength, followed by fiber reinforced splint retainer group, whereas 3M multi-strand wire had the least shear bond strength.

Keywords: shear bond strength, lingual retainer wire, fiber reinforced composite, adhesive.

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Introduction

After orthodontic treatment finished, most of problems faced by the orthodontist are relapse and high rate of returning back of the deviation and some rate of crowding after fixed lingual retainer wire bonding.[1] This has bad consequences on the treatment result. The reason for these problems may returned to several reasons, the most important is the wire material used in the fixation and adhesive used in addition to the technique used to retain and stabilize the lingual retainer wire. Due to increase the occurrence of these problems by a significant proportion of most orthodontists and to search for the main reason behind the occurrence of this problem, we conducted this modest laboratory study.[2]

Retention consider as the major step for stabilization the teeth after finishing the orthodontic treatment to maintain the moved teeth in the new position.[3] Thus, the result must remain

corrected after treatment, providing stability to ensure the success of treatments.[4] Here the most reasonable choice of stabilization clinically is to fixed lingual retainer which gives the guarantee that the anterior teeth remain firmly in their new location, bonding lingual retainer consider a good way to keep the teeth in place for a long time. [5]
Despite the good result of the retainer staying in place for a long time and the positive influence of it on the treatment result, a break may occur more times in the adhesive material and the retainer separates from the surface of the tooth leading to unsatisfactory results if it is not interfered quickly to fix the problem which are mostly happened and lead to failure of clinical retainer work.[6] The main factor that should be considered to have a long term successful lingual retainer in its position are; material used in construction of the retainer(stainless steel, FRC, etc.), adhesive material used for bonding of retainer, number of teeth bonded and the location on the lingual site of the teeth that the retainer bonded to it(cervical or incisal).[7]
With the invention of the acid etching in orthodontic practice, retainer bonding provided new retention alternatives.[8] Conventional lingual bonded stainless steel retainers have been made of high dimension, round/rectangular wires fixed to the canines only. Later on thin, flexible multi-stranded wires commonly0.0195″ or 0.0215″ were bonded to each tooth from canine to canine.[9]
The multistranded wires are recommended for lingual bonded retainers because of having their regular surface that offers good mechanical retention for the wire, which permits the physiologic tooth movement.[10] The failure of bonded lingual retentions, may occur due to microcracks within the adhesive. Therefore, the wire-composite combination may be the factor for the success of bonded lingual retainers.Fiber Reinforced Composites (FRCs) have been recommended for passive applications. [11] Alternatively, FRC were introduced to replace stainless steel wire retainers because its adhesion with the adhesive is chemical instead of mechanical adhesion.[1-12] This lead to reduce the extra adhesive material when used with metal wire retainer that has different physical characteristics[2]**.** Splinting teeth with reinforcement fibers that can be embedded in composites has gained popularity in last years because FRC containing various fibers such as carbon, polyaramid, polyethylene, and glass has received increasing acceptance as restorative materials.[13, 14]
The polyethylene fiber material adapted easily to dental contours and could be manipulated during the bonding process. It also has acceptable strength because of integration of fibers with composite resin that leads to good clinical longevity.[13]
The aim of this in-vitro study was to evaluate and compare the bond strength and detachment force (shear bond strength-SBS) of three different fixed lingual retainers (two types of stainless steel wires and glass fiber reinforced composite) using a specific retainer composite and analyze the fracture modes of different retainers' wire-adhesive combination.

Materials and methods

Specimen preparation. One hundred twenty caries-free and structurally intact enamel surface human extracted maxillary premolar teeth of patients undergoing orthodontic treatment were collected and divided into three groups of 40 (20 pairs) of teeth for each group. Teeth were evaluated under blue light transillumination to determine that the enamel were free from any defects like caries on the enamel surface, crack lines or any evidence of surface deformities, no mechanical procedures were done leading to alteration in tooth structure and no injury with chemical material like bleaching agents; they were stored in distilled water with 0.1% thymol at room temperature for maximum of 1 month.to prevent bacterial growth, the water was changed weekly.[15]

Three different retainers wires were used in this study(three study groups) which were: Group A: Speed dental orthodontic fiber reinforced composite (FRC) splint korean (1 mm x 200 mm - FS-2), Group B: 3M Unitek coxial 0.0195" wire USA, and Group Cdb Straight-8 braid flat soft wire 0.028 x 0.008 inches UK(Figure 1).

Before bonding procedure, the roots were removed and cut by disk bur under water cooling in order to be simple to embed the crown in the small size plastic mold, then the remaining crowns were prepared by cleaning and removing remnants of soft tissue and plaque by ultrasonic-scaler with pumice fluoride-free (Zircate Paste, Dents-

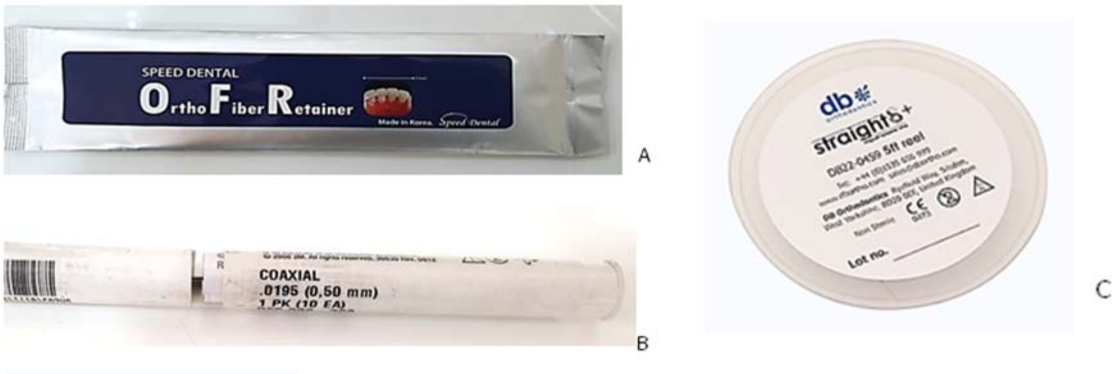

Figure 1: types of retainers used in the study.(A)Speed dental orthodontic fiber reinforced composite(FRC) splint korean ;(B) 3M Unitek coxial 0.0195" wire USA;(C) db Straight-8 braid flat soft wire 0.028 x 0.008 inches UK

Bonding procedures. Randomly the specimens of the study were divided into three groups of 20 blocks of pair of teeth (Figure 2). The lingual teeth surfaces of each tooth were etched with a 37% ortho-phosphoric acid gel (Ivoclar-Vivadent; Schann, Liechtenstein) for 30 seconds according to the manufactured instruction. The teeth were then rinsed with water from a triple syringe for 30 seconds and dried with air source from triple syringe for 20 seconds. For all teeth that were etched, the frosty white appearance of etched enamel was noticed.

The three different retainer's wires were bonded to the lingual surface of the teeth by specific adhesives (Transbond LR, 3M USA) (Figure 3-A).

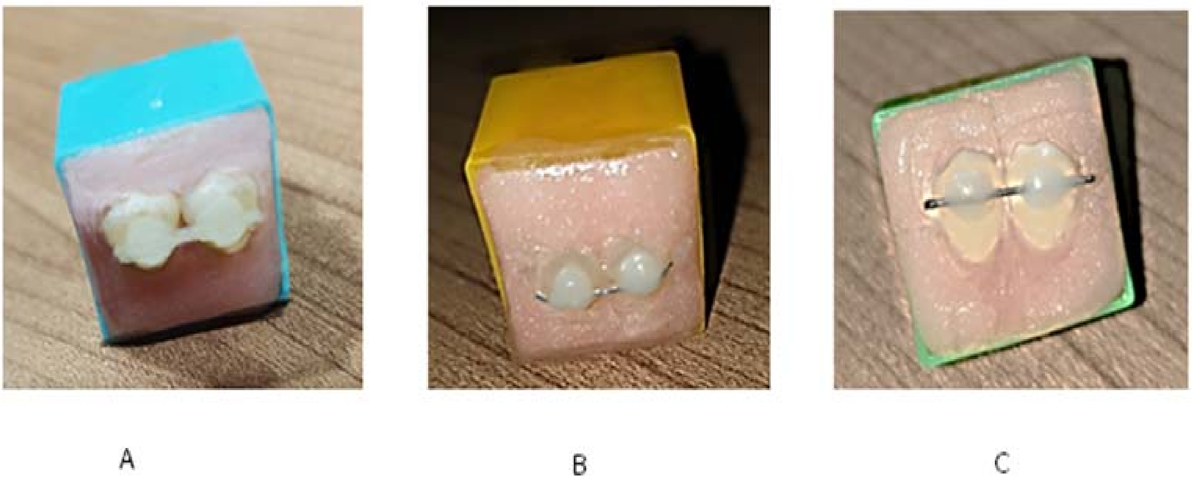

Figure 2: Sample groups. (A) (FRC) splint block ;(B) 3M Unitek coxial wire block;(C) db Straight-8 braid wire block.

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To standardize the bonding procedure, all retainers had a length of 15 mm. The wire was passively placed on the conditioned tooth surface that it was parallel to mold base, we used a dome-shaped mold, Mini Mold (Orthoclassic-USA) which it has an indentation in the center which let the wire to be placed in the middle of the retainer adhesive to standardized the amount of adhesive used for bonding to position the retainer guaranteeing bonding surfaces of 4 mm in diameter with a maximum depth of 1.5 mm located 4 mm apart from each other (Figure 4).

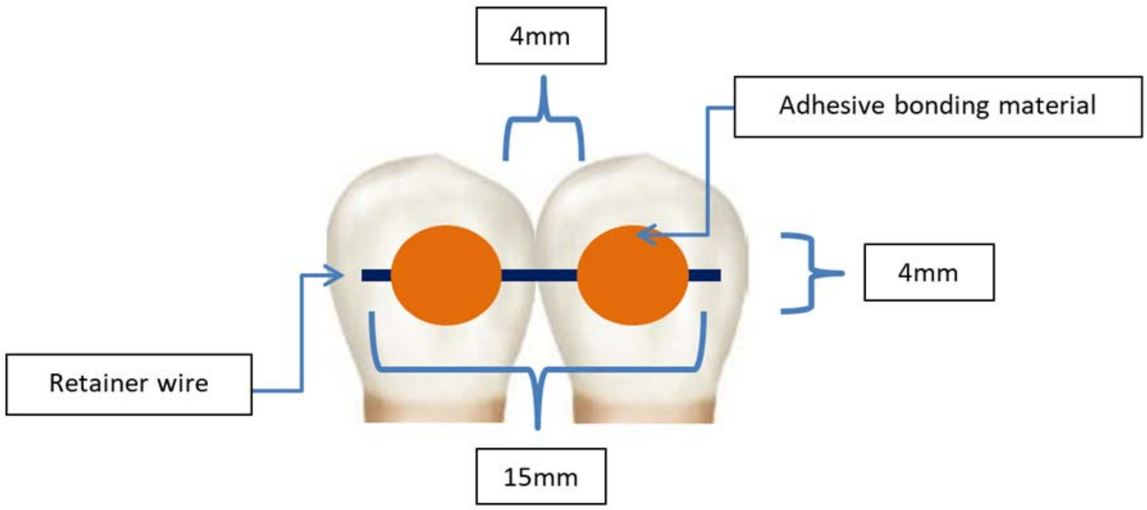

Figure 4.Schematic drawing of experimental design

The adhesive was applied using wire bonder tips, the curing performed with Denjoy, DY400-4(7W); 2000-2400 mW/cm2 led curing Light Emitting Diode for 40 seconds placed at the mesial, distal, occlusal and gingival aspects for 10s each. The power output was checked with a radiometer constantly after curing of every group (every 15 samples). Another layer of 3M Espe Filtek Ultimate Flowable composite resin was applied covering the fiberglass completely according to the manufactured instruction for bonding of FRC, and light-cured for 40 seconds again with light cure unit (Figure 3-B). After curing, finishing was conducted by polishing rubber burs and discs, and then the specimens were stored for 24 hours in distilled water at 37 ^{0}C before testing.[16]

Debonding procedure. The specimens were fixed inside a holding apparatus of the Universal testing Instron machine (Terco MT-3037 - Universal Test Sweden) which in turn secured at lower jaw of the testing machine so that the sample was mounted such that the long axis of teeth was parallel to shearing force and bonded wire segment was perpendicular to the force applied for bond failure. After that, shearing blade (10 mm width and the tapered edge of 0.5 mm thickness) coupled to a movable upper part (crosshead) of testing machine. An occlusal-gingival load was applied in such way that shearing blade struck against the midpoint of the bonded wire at a speed of 0.5 mm/min, producing a shear force until bond failure and complete debonding of wires and splint from the teeth occurred. A computer, electronically connected to the testing machine, recorded maximum load required during the testing to debond the retainerand was reported in Newton (N). (Figure 5)

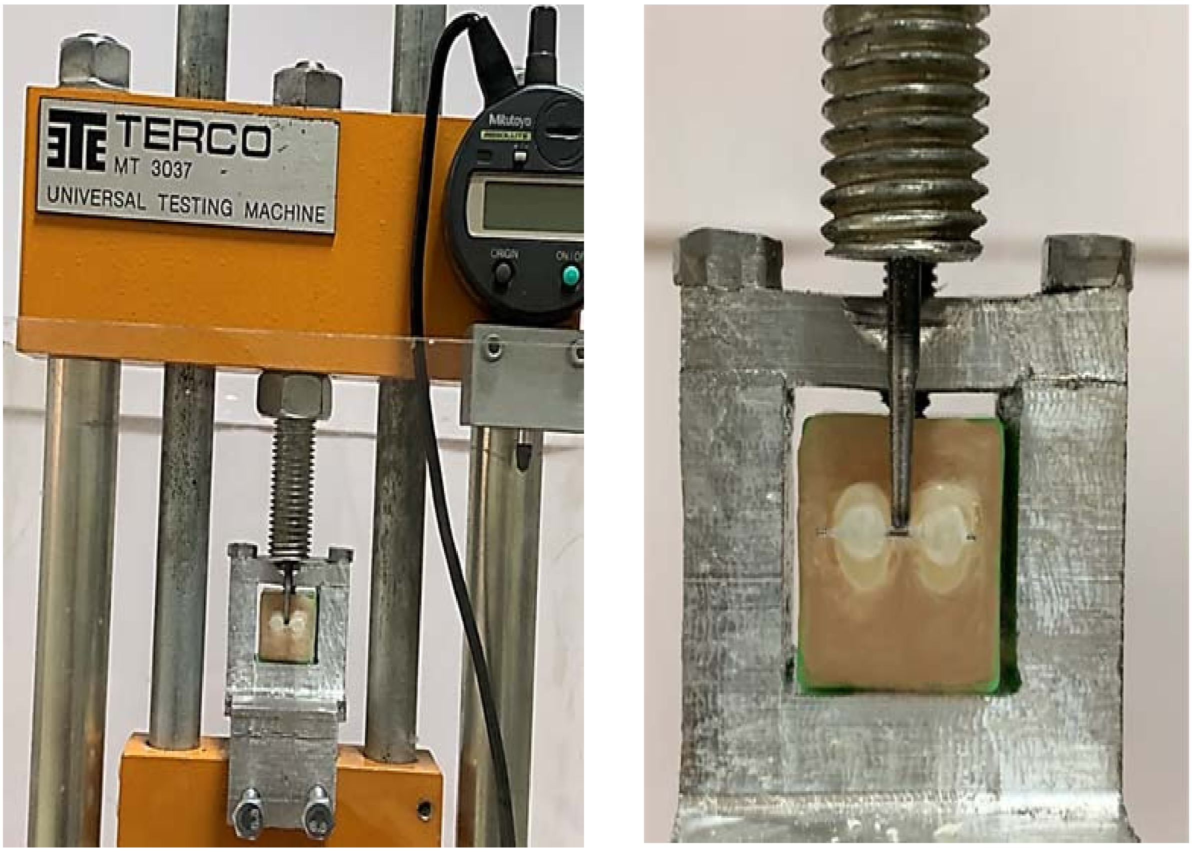

Figure 5.Experimental design for testing of shear bond strength (SBS). The force applied by the universal testing machine Instron (Terco MT-3037-Instron Universal Test Sweden) was directed along the occluso-apical axis of the incisors to simulate the initial bite force.

Adhesive remnant index(ARI). Once the retainer wire were debonded, the enamel surface of each tooth was examined under 35 time's magnification under a stereomicroscope (Leica EZ4 HD) to determine the type of failure and the amount of residual adhesive on the enamel of each tooth. The ARI scores were recorded as described by Artun & Bergland. [17]As there were two bond sites per specimen, the ARI score of both sites was recorded and then the data of the bond that failed first were analyzed. Where failure of both bonds appeared to occur simultaneously, the lower score was recorded.

The ARI has a scale range between 0 and 3:

0= no adhesive retained on the enamel (adhesive failure at composite–enamel interface);
1= less than half (50%) of the adhesive retained on the enamel (adhesive failure predominantly at composite–enamel interface).
2= more than half (50%) of the adhesive retained on the enamel (cohesive failure predominantly at the wire–composite interface).
3=the entire adhesive retained on the enamel (cohesive failure at the wire–composite interface).

Statistical analysis. Data have been analyzed using SPSS version 24. Data were described by their frequencies, range, mean, standard deviation and standard error. Shear bond strength (in Newton) of the three types of retainer bonding were analyzed by one-way analysis of variance (ANOVA) with inter-group comparison using the least significant difference (LSD). Adhesive Remnant Index (ARI) score frequencies for the three retainer bonding procedures were analyzed using Fisher's exact tests of association. A $p< 0.05$ were considered significant.

Results

Shear bond strengths. The shear bond strengths of the three groups are summarized in Table 1 and figure 6.were maximum shear bond strength was observed in group C (db Straight-8 braid flat soft wire)yielded the highest mean debonding force (130±29.6N), this was followed by group A (Speed dental orthodontic fiber reinforced composite splint korean)which was (107.5±18.9 N),and then followed by the minimum observed debonding force group B(3M Unitek coxial multi strand wire 0.0195 USA)(76±27.6 N). On comparison of the mean shear bond strength among three groups of retainers, one way ANOVA revealed statistically high significant difference between the three lingual retainer groups especially in group C which showed significantly higher results than those of two other group (A and B group).

Table 1: Shear bond strength (SBS in Newton) for three different lingual retainer bonding groups.

Group	No.	SBS (Newton)				One-way ANOVA	
		Range	Mean	SD	SE	Overall	Inter-group comparison (LSD)
A (f.glass)	20	70 - 140	107.5	18.9	4.22	*P*<0.001	A vs B: *P*< 0.001
B (3M)	20	40 - 130	76.0	27.6	6.17		B vs C: *P*< 0.001
C (db)	20	60 - 180	130.0	29.6	6.61		C vs A:*P* = 0.008

SD: standard deviation; SE: standard error; ANOVA: analysis of variance; vs: versus; LSD: least significant difference.

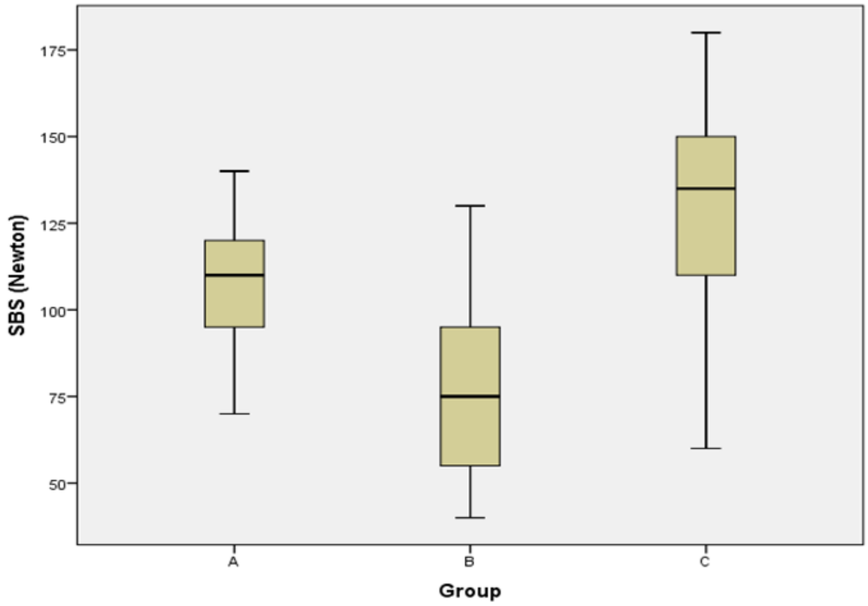

Figure 6. Box plot of shear bond strength (SBS in Newton) for three different lingual retainer bonding groups.

Adhesive Remnant Index (ARI)after debonding. Table 2 represents the site of the bond that failed. ARI of the bond site that firstly failed in each specimen group was analyzed by Fisher's exact tests, there was highly significant difference between the distribution of the ARI score between bond and rebond events in the three groups of the lingual retainer overall, but there was non-significant difference between group C (db Straight-8 braid flat soft wire) and group B(3M Unitek coxial 0.0195" wire)(P = 0.176).

Table 2: Residual adhesive ratings according to ARI (Adhesive Remnant Index) score frequency for three different retainer wire bonding procedures.

Group	ARI				Fisher's exact tests	
	0	1	2	3	Overall	Inter-group comparison
A (f.glass)	3	12	5	0	P< 0.001	A vs B: P < 0.001
B (3M)	0	1	8	11		A vs C: P< 0.001
C (db)	0	0	4	16		C vs B: $P = 0.176$

Discussion

In the present study, the clinical bite situation is simulated and similar to putting a vertical thrust on the retainer. Many authors like Reicheneder et al, 2009[18] found that a vertical thrust yields the highest values of shear bond strength (SBS) compared to a tensile force in horizontal or vertical orientation. However, SBS not only depends on the direction, but also depend on the site of the applied force. Some studies have demonstrated that the lowest values of SBS occur when the force is applied to the interdental wire segment. [9] Here we select this point of segment to determine the lowest strength required for retainer debonding. This study was done to examine the force required (shear bond strength-SBS) to debond a segment for three types of bonded lingual retainer wire bonded by special type of orthodontic adhesive when vertical force was applied to an interdental segment of wire.

In the present study a greater force was required for debonding of db Straight-8 braid flat soft wire group which show the highest SBS value followed by fiber glass reinforced group and the last group was coaxial multi-strand stainless steel group, and there was a high significant difference between their debonding forces (P<0.001). According to Reicheneder et al in the study done at 2014[2], they supposed that increased strands count of the retainer wire has generally positive effects on its clinical stability. As this type of flat soft 8 time braided wire that tolerated significantly higher SBS provide improved mechanical retention due to their interlaced nature and due to its softness and flat design that adapted to the lingual surface of the teeth when bonded which let the thinner side of the wire to face the vertical load movement of the cross head of instron machine. There was large difference between the dead soft flat (0.028 x 0.008 inches) wire with a high degree of annealing and the coaxial 0.0195 multi strand stainless steel wire which could be also attributed to the nature of the retainer material.[19] Respond is a dead-soft wire, which means that it is passive and does not exert any active force when adapted to the tooth surface, means there were no accumulated force and stress helped in accentuating retainer bond failure; here our finding is similar to the study done by Singh A et al, 2019.[20] On the other hand, coaxial 0.0195 multi strand stainless steel wire is a plain coaxial wire, which might have residual forces when twisting it during demonstrating and manufacturing process. These stored forces can lead to the accumulation of stresses at the points of mastication loads, causing debonding and failure of the bond between wire and adhesive,[19] and this revealed retaining the entire adhesive on the enamel in case of coaxial wire (Table 2).The combination of Transbond LR and db Straight-8 braid flat soft wire produced a higher shear bond strength value than the other two other groups of retainers due to the good flowability and viscosity of the Transbond adhesive around the wire that leading to increase mechanical retention beside that the flexibility of the soft db straight wire that adapted better to the tooth enamel surface. The same finding was obtained by Reicheneder et al, 2014.[2]

Many Authors evaluated both multistranded wires and fiber reinforced composites used for post-orthodontic retention, as in study done by Scribante et al at 2011,[21] which resemble the finding of our study result where the mean of shear bond strength of the glass fiber reinforced was 107.5±18.9 N while for coaxial multi -strand stainless steel wire was 76±27.6 N which was consider a high significant difference. Some studies obtained different results from our finding like that obtained by Reicheneder et al at 2014,[2] were the fi-ber-reinforced retainers showed less SBS (37.02 N)than Wildcat Twistflex wire (63.84 N),but this may be due to a different adhesive that were used with Wild cat Twistflex wire that used Stic-flow composite , while they used the same our bonding adhesive for fiber-reinforced which was Transbond LR and this may be one of the reasons because the viscosity of Stic-flow composite flowable is less than Transbond LR, beside that the sample size of their study groups were 10 specimens for each group while our study groups were 20 specimens for each group which may effect on the result. On the other hand, a clinical study done by Bolla *et al* at 2012 that follow up patients for 6-year showed no significant differences between FRC and multi stranded wire retainers; the results of this study showed that FRC retainers could be an alternative or instead of multi stranded wire retainers in many cases.[22] A similar finding obtained by Sfondrini *et al* at 2014,[24] in longitudinal prospective study, when the rate of detachment was 17.73% for flexible stainless steel wire and 11.25% for glass fiber-reinforced resin retainer. In another clinical pilot study done by Kumbuloglu et al at 2011[25] in a period of more than 4.5 year of E-glass FRC resin splint clinical follow up where the survival rate was 94.8%.In accordance with the findings obtained by our sudy, a study conducted by Alavi S, and Mamavi T in 2014, [26] concluded that glass FRC group had significantly higher load compared to stainless steel wires. Foek et al study on the fatigue resistance and debonding force which done in 2013[26] supposed that the using FRC adhesive resin complex instead of stainless steel wires might improve stability. The lower bond strength of stainless steel wire in contrast to FRC could be due to the fact that wire does not chemically bond to the dental resin and is only embedded in it.[27]

ARI(adhesive remnant index) in both two stainless steel wire groups, most of the adhesive retained on the enamel, the failure was at the wire composite interface (cohesive failure), this result was resemble to an extend the result obtained by Foek DL et al at 2009, [18] where showed more adhesive failure was adhesive (between the enamel and the composite) that most of the composite left on the enamel surface at different degrees in stainless steel groups when compared with FRC groups, this is may be due to that the two materials, stainless steel wire and composite resin, have different physical properties, there were only mechanical retention between them and subsequently the loading force on the retainer result in internal cracks in the resin pad over and under the wire after applying the pressure from the instron cross head leading to cohesive failure. This is expected to become clearer in reality also when the adhesive material is on the retainer; the failure of the stainless steel wire -composite interface is due to two main factors. First, due to abrasion happened because of food chewing and tooth brushing, the resin small pad cover the retainer become thin and which in turn lead to detachment of the retainer from the resin pad.[26,28] Second, during the physiological tooth movement, there is the possibility of internal cracks incidence due to constant movement of the retainer inside the overlying and the underlying resin pads which is related to wire/composite failure.[18, 28] Similar failure happened in study done at 2004,[29] by Radlanski and Zainwhen when the failure was largely at the composite/ wire interface (cohesive failure) and suggested that the bond strength of the wire/ bond/enamel combination is weakened by the presence of ‘freely tensioned’ wire in the bonded retainer system and that such sections should be kept as short as possible to reduce the impact of tensile forces.[16] While in case of FRC group, most of the retainer failure of bond had occurred at composite/enamel interface and there were a highly significant difference between ERC retainer wire failure side scores and the other two stainless steel wires groups ($P < 0.001$).The clinical efficacy of FRC retainers may be based on the internal structure of the complex, the resin of the matrix and the adhesive system integrate with fibers. The homogeneous structure of integrated resin matrix, adhesive, and fiber might absorb and dissipate mechanical stresses along the whole FRC retainer which subsequently lead to failure of the whole retainer with adhesive bonding from the enamel surface. [23,30] The adhesion between the FRC retainer and the composite is a chemical adhesion and should be in theory better than the adhesion between a stainless steel wire retainers and composite, which is a mechanical adhesion.[18]

Reynolds IR in 1975,[32] determined that materials for acceptable clinical use in orthodontic treatment should be able to resist forces of 6-8 N. Waters NE in 1980,[33] noticed that the normal range of oral forces is 3-18 N. Although it can be assumed that the fixed retainer wires will not be subject to oral loading to the same extent. In our study the SBS of all tested retainer systems including the fiber reinforced systems and stainless steel wires exceeded these values and should therefore show clinically sufficient shear bond strengths. As the bond strength in this study were evaluated under in-vitro conditions and it must be remembered that the data analysis from this study is relevant to the in-vitro application of the specific adhesive, Transbond LR, etching gel system, 3M Espe Filtek , and does not account for the many in-vivo dependent variables like temperature, saliva, cyclic loading from mastication, or microbial effects[18], thus the results cannot be completely extrapolated to the oral situations and condition, which is one of the limitations of this study. Also, stress was applied in only one direction not like in the oral field where the load direction may be in many other directions. In-vitro findings have been suggested that it apply strongly to the in-vivo experience because of the less favorable working conditions. Another limitation of this study may be the retainer itself which has short length compared to the clinical situation in patient mouth was the retainer is longer. However, more clinical studies are required to determine the ideal wire dimensions for lingual bonded retainers.[23]

Conclusion

Within the limitations of this in-vitro study, the present study demonstrated: Flat dead straight 8 stainless steel showed the highest bond strength (SBS), followed by glass fiber reinforced composite (FRC), while Unitek coxial multi strand wire group exhibited the least bond strength. With significant difference among all the three groups.

There was variation in failure modes between the experimental groups as follow: In FRC most of the bonding failure site were adhesive failure while in both types of stainless steel wire failure were cohesive type with significant differences in debonded locations (ARI) scores from FRC group retainers.

Conflict of Interest

The authors reported no conflict of interests.

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