

Comparative Evaluation of Failure of Three Different Aged Orthodontic Bonded Retainers Related to Vertical Loads (in vitro study)

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Abstract

Introduction: Failure of orthodontic bonded retainers may affect the orthodontic results and cause relapse.

Objectives: To compare in vitro the effect of vertical load on failure of three different bonded lingual retainers: Flat braided wire "Bond A. Braid", Dead soft wire "RESPOND", Fiber reinforced composite "Infibra Ribbon". Bonded with Tetric-N Flow adhesive system.

Materials and Methods: Ninety mandibular incisors were used in the study, thirty specimens ($N=30$) in triads divided into 3 groups ($n=10$ for each group). Roots of the incisors were covered with elastomeric impression material to mimic periodontal ligaments elasticity and embedded in triads in acrylic resin blocks. They were randomly divided into 3 groups to receive the following retainer wire materials: Group A (Flat braided wire "Bond A. Braid"), Group B (Dead soft wire "RESPOND"), and Group C (Fiber reinforced composite "Infibra Ribbon"). And these retainer wires were bonded to the lingual surfaces using Tetric-N Flow adhesive system. The three groups were subjected to 10,000 thermal cycles between 55°C & 5°C using a thermocycling machine. Each specimen was subjected to loading forces at the incisal edge of the middle incisor for

125,000 cycles. Then failure forces were measured using a Universal Testing Machine at a cross head speed (1mm/min) applied on the wire of the interproximal segments. Failure sites were determined and the adhesive remnant index (ARI) was observed using a stereomicroscope at ($\times 20$) magnification.

Results: Mean debonding forces were 46.27 ± 12.28 , 36.03 ± 6.09 , 30.09 ± 15.73 N for Groups A, B and C respectively, presenting significant difference between the groups ($p < 0.05$). The highest value for the mean force was found for the Bond-A-Braid (group A) and the lowest value for the mean force was found for the FRC (group C). There was no statistically significant difference in displacement among test groups. There was no fracture occurred of any wire. There was no significant difference between the distribution of the ARI score between the three groups ($p=0.322$). The ARI scores were observed under the optical stereomicroscope showing multiple failures at the composite-wire interface and the tooth-composite interface.

Conclusions: There was a significant difference between "Bond A. Braid" wire and "FRC" where "Bond A. Braid" had the highest debonding forces and the "FRC" had the lowest debonding forces. There was no significant difference in displacement of the

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retainers between the three groups. There was no significant difference between the ARI of the lingual retainer systems and types of failure as well.

Keywords: retainer, retention, wire, bonding, lingual, aging, relapse.

INTRODUCTION

Retention is a mandatory process following orthodontic treatment to avoid relapse as a result of periodontal fibers elasticity and to permit alveolar bone remodeling. The amount of relapse is unpredictable and varies according to the case. Long term studies have proven that bonded lingual retainers were effective in maintaining lower incisors in the post treatment new position.⁽¹⁾

Lingual retainers are favored specially when the post treatment inter-canine distance is to be preserved and the periodontal supporting tissues are partially lost.^(2, 3) Although favorable results have been presented concerning the survival of lingual retainers, the retainer material to be broken and the fixing adhesive to be debonded from the tooth surface are still commonly occurring failures clinically.^(3, 4)

There is no clear defined reason behind failure of lingual retainers. The three most stated problems for metal retainers were the breakage of the wire, failure of wire-composite interface and detachment of adhesive pads at the enamel-composite interface.^(2, 5, 6)

The survival rates and failure rates as well of lingual retainers have a great controversy clinically, testing different retainer materials in vitro clarifies such results.^(4, 7)

There is a great variability in the sites of failure of bonded retainers, which was reported

as following: at the composite-enamel interface, at the composite-wire interface (adhesive failure), combination of both (compound failure), and fracture of the wire as a result of stresses.⁽⁵⁾

The most common failures that reported in literature occurred in the first 6 months after bonding, while the patient's age and experience of the operator have no effect on the rate of failure.⁽⁶⁾

The aim of this study was to evaluate and compare the failure of bonded lingual retainers subjected to vertical loads simulating the masticatory forces following: thermo-cycling and load-cycling mimicking a period of six months on the failure of:

- A. Flat braided wire "Bond A. Braid"*
- B. Dead soft wire "RESPOND"**
- C. Fiber reinforced composite (FRC) "Infibra Ribbon"***

Bonded with "Tetric N flow"**** adhesive system.

The **null hypothesis** of this study was that there was no difference in the effect of vertical forces on failure between the three types of bonded fixed retainers

Material and Methods

The experiment was conducted in the Faculty of Dentistry, Alexandria University (for thermal and mechanical aging) and Mubarak City for Scientific Research and Technological Applications "SRTA" (for testing samples using the universal testing machine). A sample size of 10 specimens per

* (Hilgers) Reliance, USA

** ORMCO, Italy

*** Biolurin, Italy

**** Ivoclar vivadent, USA

group (number of groups =3) (total sample size = 30) was the enough required sample to detect a standardized effect size of 0.506 of the primary outcome.^(8,9) Each specimen of the study consisted of three lower incisors freshly extracted due to periodontal problem or orthodontic purpose, and fixed in an acrylic block then divided into three groups. Ninety lower human incisors were collected from the oral surgery department and used in the study.

Inclusion criteria

- Teeth free from any cracks or defects with visual inspection.
- Free from caries and restorations with intact lingual surfaces.

Immediately after extraction the teeth were thoroughly cleaned under running water. All calculus and soft tissue remnants were removed using a hand scaler. The teeth were then stored in distilled water at room temperature to avoid dehydration, and they were cleaned with water slurry of pumice and brush before mounting.

Triads of teeth were matched to make a contact area to mimic the intraoral situation noting that the middle tooth in each sample was having more or less the same mesio-distal dimension (5mm) as it will be subjected to the force of cyclic loading, this was done after measuring the mesio-distal dimension of all teeth in the sample and was noted that they were ranging from 3.5mm to 6mm; So the teeth with almost the mean dimension were taken.

The roots were dipped into melted wax 2mm below the cemento-enamel junction (CEJ) in order to create a 0.5 to 1 mm thickness of wax layer. The triads were held parallel to each other and perpendicular to the base of the mold using the specially milled

copper holder attached to the surveyor and in the midway between the ends of the copper mold.

Chemically cured acrylic resin was placed into the rectangular copper mold and was manipulated according to the manufacturers' instructions using the drop method technique.⁽¹⁰⁾

After complete polymerization the wax was washed from the root surface and resin block using boiling water, and the teeth were removed from the mold.

In order to simulate the periodontal ligaments and normal tooth mobility: An elastomeric material "light body" was placed in the resin molds, the teeth were re-inserted into the mold and the excess elastomeric material was removed with a scalpel blade after setting.

In all groups, the lingual surface of the teeth was cleaned with pumice and brush and dried using air spray then etched with a 37% phosphoric acid "Heliosit orthodontic"* at the area which will receive the retainer for 30 s and then rinsed thoroughly using an oil-free air-water spray for 20 s. The enamel surfaces were air dried until they appear frosty.

A filler- and solvent-free light-curing bonding agent (Tetric N flow)⁽¹¹⁾ was applied with a micro-brush on the acid-etched enamel surface and blown into a thin layer using an air spray. It was then light polymerized for 40 s with a LED light curing unit** from all directions. The irradiation distance between the exit window and the resin surface was maintained at 2 mm to obtain adequate polymerization.

A commercially available dome shaped

* ORMCO, California, USA

** Guilin Woodpecker Medical Instrument CO., LED

mold (MINI-MOLD)^{***} were used to standardize the amount of composite used for each bond.⁽¹²⁾

The mold has a groove that allows the operator to locate the composite so that the wire was in the middle of the composite. Flowable resin composite (Tetric N flow) was applied to the enamel surface and the respective material used for each group was placed on the bed of the flowable composite, arranged horizontally on the largest area of the lingual surface of the incisor, the materials were rewetted with the bonding agent and then covered with the flowable resin inside the mold.

Excess composite was removed from the margins of the mold before curing for 40s on a distance of 2mm.

For the divided groups, the first two groups of wire were cut by the long handle universal cutter and the third group by using the Ribbond fiber cutter^{****}.

Aging Procedure

Thermo-cycling: All specimens were subjected to 10000 thermal cycles between 55°C & 5°C using a thermo-cycling machine, with a dwell time of 60 s & a transition time of 15 s which simulates a period of six months in the patient's oral environment. **Figure (1.A)**

Load-cycling : The same specimens were mounted in a load cycling machine to receive an intermittent load of 125,000 cycles at the incisal edges of the middle incisors (simulating the masticatory forces during 6 months).⁽¹³⁾ **Figure (1.B)**

Failure Analysis

Any failure during the aging process was

recorded. The samples were then placed in a Universal Testing Machine, the crosshead speed was set at 1 mm/min. The applied force was directed vertically along the occluso-apical axis of the incisors using a specially milled copper fork directed at the center of the wire of the interdental segments between the triad of teeth; And the maximum load necessary where the initial failure occurred was recorded in Newton(N).⁽¹²⁾ **Figure (1.C)**

The maximum displacement (wire deformation) occurred before failure was recorded too using the same machine. The mode of failure for retainers was evaluated by using an optical stereomicroscope at a magnification (x20).

In cases of composite failure the adhesiveremnants were recorded while blinding the study groups. According to the adhesive remnant index (ARI), the failures were coded and ranked from 0 to 3, if the failure occurred on more than one tooth, the mean of the adhesive remnant was calculated. Noting that the ranking was done by single observer.

- **Score 0:** No adhesive remained to enamel
- **Score 1:** Less than 50% of the adhesive remained on enamel
- **Score 2:** More than 50% of the adhesive remained on enamel
- **Score 3:** All adhesive remained on enamel

Types of failure:

By using stereomicroscope, the types of failure were recorded whether at the wire itself or at the composite-wire interface or at the composite-enamel interface.

*** Dynaflex, Hauge, Netherlands

**** Ribbond, Seattle, WA, USA

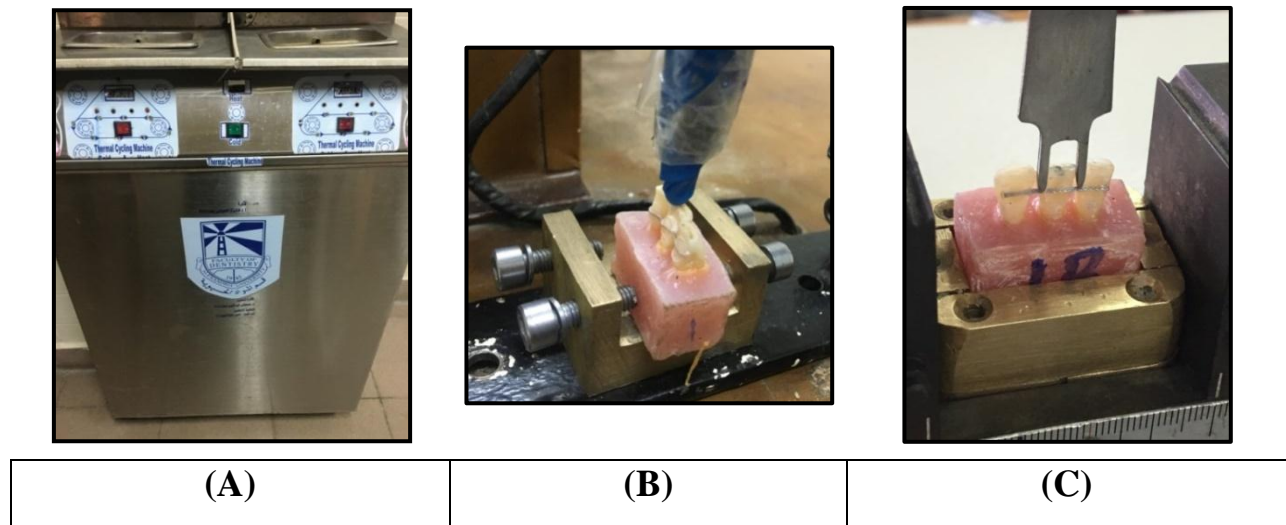


Figure 1: (A) Thermo-cycling Machine. (B) Load-cycling Machine. (C) Testing a specimen on a universal testing machine.

Statistical analysis of the data

Data were fed to the computer and analyzed using IBM SPSS software package version 20.0. (Armonk, NY: IBM Corp) Qualitative data were described using number and percent.

The used tests were:

Chi-square test: for categorical variables, to compare between the three groups.

Monte Carlo correction:

Correction for chi-square when more than 20% of the cells have expected count less than 5.

F-test (ANOVA): for normally distributed quantitative variables, to compare between more than two groups.

Kruskal Wallis test: for abnormally distributed quantitative variables, to compare between more than two studied groups.

Results

All samples survived 10000 thermal cycles between 55°C & 5°C and 125,000 cyclic loading without any retainer failures. Mean debonding forces were 46.27 ± 12.28 , 36.03 ± 6.09 , 30.09 ± 15.73 N for Groups A, B and C respectively, presenting significant difference between the groups ($p < 0.05$) (**Table 1**). The highest value for the mean force was found for the Bond-A-Braid (group A) and the lowest value for the mean force was found for the FRC (group C)

Table (1): Force required to fail bonded retainer from incisors *in vitro* [in Newton]

Force (N)	Group A (Bond A. Braid) (n = 10)	Group B (RESPOND) (n = 10)	Group C (FRC) (n = 10)	p
Mean ± SD.	46.27 ± 12.28	36.03 ± 6.09	30.09 ± 15.73	0.019*
Sig. bet. grps.	p ₁ =0.158, p ₂ =0.015*, p ₃ =0.521			

Each 2 groups was done using **Post Hoc Test (Tukey)**

p: p value for comparing between the studied groups

p₁: p value for comparing between **Group A** and **Group B**

p₂: p value for comparing between **Group A** and **Group C**

p₃: p value for comparing between **Group B** and **Group C**

*: Statistically significant at $p \leq 0.05$

Retainer Displacement

(Wire Deformation)

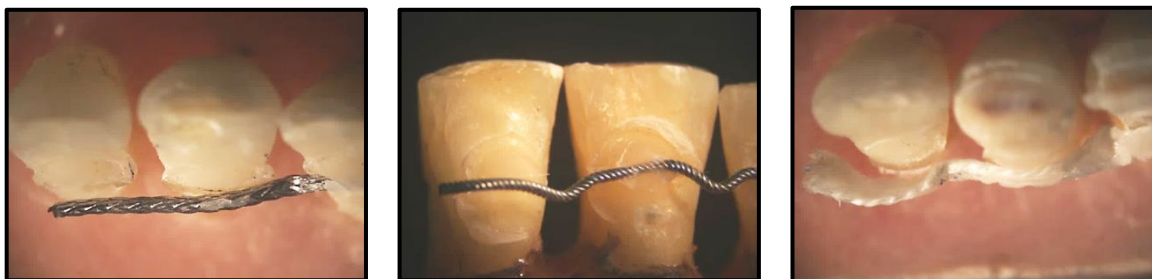
Descriptive statistics and group comparisons for wire displacement

measurements are given in **Table 2**. There was no statistically significant difference in displacement among test groups. (**Figure 2**)

Table (2): The amount of wire displacement measured by the universal testing machine after failure of the retainers of the three groups unit: mm

DISP	Group A (Bond A. Braid) (n = 10)	Group B (RESPOND) (n = 10)	Group C (FRC) (n = 10)	p
Mean± SD.	1.28 ± 0.77	1.0 ± 0.43	1.34± 0.47	0.387

p: p value for comparing between the studied groups

**Figure (2): Retainer displacement in the three different groups under the stereomicroscope ×20 magnification**

Adhesive Remnant Index

The ARI of the failed site or sites in each sample was analyzed. The ARI of the three groups tested are presented in **Table 3**. There was no fracture occurred of any wire. There was no significant difference between the distribution of the ARI score between the three groups (p=0.322).

The ARI scores were observed under the optical stereomicroscope showing multiple failures at the composite-wire interface and the tooth-composite interface as showed in **Figure 3**.

The ARI was scored on single tooth or multiple teeth(mean)

Table (3): Comparison between the three studied groups according to ARI

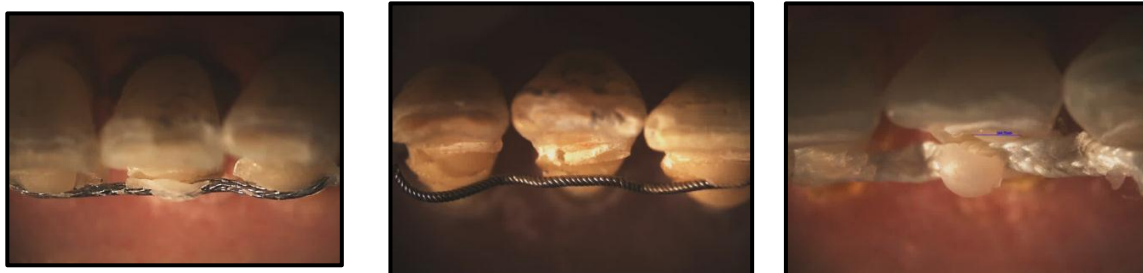
ARI	Group A (n = 10)		Group B (n = 10)		Group C (n = 10)		p
	No.	%	No.	%	No.	%	
Score 0	0	0.0	2	20.0	1	10.0	MC p=0.147
Score 1	0	0.0	0	0.0	1	10.0	
Score 2	6	60.0	2	20.0	6	60.0	
Score 3	4	40.0	6	60.0	2	20.0	
Min. – Max.	2.0 – 3.0		0.0 – 3.0		0.0 – 3.0		0.322
Median (IQR)	2.0 (2.0 – 3.0)		3.0 (2.0 – 3.0)		2.0 (2.0 – 2.0)		

χ^2 : Chi square test

MC: Monte Carlo

H: H for Kruskal Wallis test

p: p value for comparing between the studied groups



(A) **(B)** **(C)**

Figure (3): (A) The ARI under Optical Stereomicroscope for group A showing score 2 & different failures were apparent in each tooth. (B) Group B is showing score 3 in 2 teeth out of three. (C) Group C is showing score 2 “most of the adhesive remnants on the tooth surface” and fibers of the retainers are attached to them partially.

Discussion

Relapse after orthodontic treatment composes a problem and that was shown in long-term stability studies. So the maintenance of treatment results through prolonged use of retainers has been recommended.⁽¹⁴⁻¹⁸⁾ Fixed lingual retainers can prevent post-treatment changes and late crowding. Bonded retainers are mostly used to prevent anterior teeth crowding.⁽¹⁹⁾ Patients with fixed retention show consistently better alignment at 5 and 10 years post-treatment than those patients without fixed retention.⁽¹⁹⁾

It is a known fact that there were different protocols for investigations of bond strength, and the scientific comparison is difficult due to this lack of standardization. Very few authors have examined the wire interdental segment as most of the studies published in literature were testing materials by one loading method applied directly at the bonding site of the orthodontic attachment.^(20,21)

The primary aim of this study was to evaluate the failure of three types of bonded retainers frequently used following: thermo-cycling and load-cycling, mimicking a period of six months in vitro. The secondary aim of this study was to analyze failure types and amount of wire deformation before failure. Non of the experimental retainers failed during cyclic loading and thermal loading but the material types showed different failure forces and multiple failure sites occurred. The null hypothesis that there was no difference in the effect of vertical forces between the flat braided wire, the dead soft wire and the fiber reinforced composite was rejected because $P \leq 0.05$.

Three types of wires and one type of adhesive were tested in this study. It was concluded in a previous study that retainer wire selection was more important than composite selection.⁽²²⁾ We selected these wires as they were recommended in literature.^(3,20,23)

The type of adhesive was an important factor in the failure mechanism of lingual retainer wires. In the current study, we decided to standardize one type of adhesive which was appraised in literature "Tetric N Flow" as it showed better bonding values and exhibited wire pull out resistance values comparable with other types of adhesives, and also better in polishing characteristics than macrofilled composites, has a very high elasticity and withstand the forces applied on the retainer system.^(11,20, 24,25)

The human lower incisors have a high individual variability like in age, shape and amount of mineralization. That's why using them in studies is facing negative judgement. Also it is very logic to mimic the natural individual variation of those teeth, as they are the ones which bonded to fixed retainers in most of the cases. We standardized the amount of composite placed over the teeth and the wires tested using commercially available molder (Mini-Mold) to overcome the differences in size and morphology of the teeth used in the study.⁽¹²⁾ Also to simulate the periodontium and its flexibility, the use of elastomeric impression material on the roots of the teeth was a good solution during application of forces.⁽¹⁰⁾

Most of the in vitro studies used lower incisors, they used them in the form of a single tooth sample^(20,24) or a paired teeth sample,^(12,22,23,25-27) our study is the only one used a triad of teeth bonded together to

increase the surface area subjected to the force applied to mimic the oral situation, to be able to apply the load cycling to the middle tooth and to have the chance of having two interdental segments subjected together to the force by the universal testing machine. Choosing the center of the wire of the interdental segment to be the point of force application was because several authors have demonstrated that the lowest values of bond strength occur when the force is applied to the interdental segment.^(20,28)

Bond Failure:

In this study, the flat braided wire was superior to the other two types of bonded retainers and showed the highest values of debonding forces. This result was supported by previous studies handling the same type of wire in comparison with different retainer materials.^(23,24,29)

The failure types deserve more attention when comparing the performance of the tested retainer materials. In the present study, the main mode of failure was the wire-composite interface. Since the same adhesive was used for all the three groups, these adhesive failures indicate that the adhesion between the bonding resin and enamel exceeded the strength between the retainers and the adhesive .

Considering the results that the flat braided wire group had the higher debonding forces versus the FRC, it was obvious that the FRC weakened the composite/fiber interface instead of strengthening it. What happened was against what was expected from the FRC to show higher debonding forces than the wire as they have a chemical adhesive properties between the composite and the fiber, as opposed to the mechanical retentive properties of the wire. The failure behavior of FRC

material is very complicated because of its anisotropic character, as the failure occur more when the force is perpendicular to the spraying direction of the fiber.⁽³⁰⁻³⁴⁾

Retainer Displacement

(Wire deformation)

The measured displacements in association with the ARI scores may explain that the force absorbed by these flexible wires interdentally tugs the wire and cause deformation of the interdental segment. This will lead to cracks propagation inside the composite (cohesive failure), mostly in the wire-composite interface, and resultant bond failure at the composite-wire interface i.e. (adhesive failure). This was previously contended by Bearn et al (1997).

Conclusions

1. The thermal and cyclic loading did not result in any failure of the retainer wires under test.
2. There was a significant difference between Bond A. Braid wire and FRC where Bond A. Braid had the highest debonding forces and the FRC had the lowest debonding forces.
3. There was no significant difference in displacement of the retainers between the three groups.
4. There was no significant difference between the ARI of the experimental groups.
5. The combination of “Bond A. Braid” wire with the “Tetric N. Flow” adhesive could be sufficient bond for clinical use.

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