Original Article

An assessment of the impact of adhesive coverage and wire type on fixed retainer failures and force propagation along two types of orthodontic retainer wires: an in vitro study

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ABSTRACT

Objectives: To evaluate the force required to promote the failure of fixed orthodontic retainers with different adhesive (composite) coverage and to assess the presence and extent of force propagation with two different orthodontic retainer wires.

Materials and Methods: Ortho-FlexTech and Ortho-Care Perform (0.0175 inches), each of 15-cm length, were bonded on acrylic blocks with different adhesive surface diameters (2 mm, 3 mm, 4 mm, and 5 mm). The samples ($n = 160$) were subjected to a tensile pull-out test, and debonding force was recorded. Fixed retainers using two different wires and 4-mm adhesive diameter were bonded on acrylic bases resembling a maxillary dental arch ($n = 72$). The retainers were loaded occluso-apically until the first sign of failure while being video recorded. Individual frames of the recordings were extracted and compared. A force propagation scoring index was developed to quantify the extent of force transmission under load.

Results: A 4-mm adhesive surface diameter required the highest debonding force for both retainer wires with significant differences compared with 2 mm ($P < .001$; 95% confidence interval [CI]: 8.69, 21.69) and 3 mm ($P = .026$; 95% CI: 0.60, 13.59). Force propagation scores were significantly higher for Ortho-Care Perform.

Conclusions: Based on this laboratory-based assessment, consideration should be given to the fabrication of maxillary fixed retainers using a minimum of 4-mm diameter composite coverage on each tooth. Force appeared to propagate more readily with Ortho-Care Perform than with a flexible chain alternative. This may risk stress accumulation at the terminal ends with potential for associated unwanted tooth movement in the presence of intact fixed retainers. (*Angle Orthod.* 2023;93:712–720.)

KEY WORDS: Orthodontic retainer wire; Composite coverage; Unexpected tooth movement; Force propagation

INTRODUCTION

There is widespread acceptance of the unpredictable nature of posttreatment and maturational changes affecting the dentition and an appreciation that lifetime permanent retention is the most reliable way to prevent relapse.[1] Notwithstanding, studies have shown that relapse may occur irrespective of the use of fixed retainers.[2]

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Accepted: April 2023. Submitted: November 2022.
Published Online: May 26, 2023

 DOI: 10.2319/110722-765.1

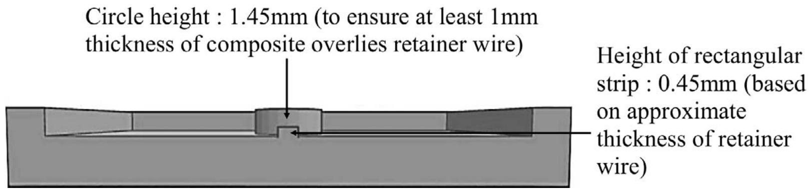

Figure 1. Cross section of 3D template.

Retainer failure may present as wire fracture or detachment at the tooth-adhesive or adhesive-wire interface. While failure at the enamel-composite junction may be attributed to moisture contamination during bonding,[3] insufficient composite or abrasion by the opposing dentition may predispose to failure at the wire-composite interface.[4,5] An increased thickness of overlying composite may increase the force required to cause retainer detachment, although any increase beyond 1-mm thickness is unlikely to provide any significant clinical benefit.[4]

Unexpected tooth movement not resembling the pretreatment malocclusion may occur in the presence of intact fixed retainers. These changes include torque differences between two adjacent incisors (X-effect), increased buccal or lingual inclination of a mandibular canine, and opposing changes of contralateral mandibular canines (twist effect).[6–9] Some potential contributors include inherent wire properties, wire distortion from masticatory forces, or lack of wire passivity during bonding.[6,10] This may result in deleterious effects to the periodontium when left undetected for prolonged periods, potentially dictating a further course of orthodontic treatment, recourse to periodontal procedures and even tooth loss in extreme scenarios.[8,11]

There is, therefore, a need to find a balance among the different mechanical properties (strength, flexibility, and force propagation potential) when deciding on the choice of retainer wire. This study aimed to evaluate the effect of adhesive coverage and wire type on the force required to promote failure of fixed retainers and to assess the presence and extent of force propagation along two different retainer wires.

MATERIALS AND METHODS

Two wires, Ortho-Care Perform (0.0175 inches) and Ortho-FlexTech (stainless steel), were bonded using Transbond LR (3M).

Effect of Varying Adhesive (Composite) Coverage on Retainer Failure

Four resin templates each with a raised circular platform of varying diameters (2 mm, 3 mm, 4 mm, and 5 mm) were 3D-printed using an Anycubic Photon 3D printer (Shenzhen Anycubic Technology Co., Ltd, Shenzhen, China; Figure 1). Medium-body silicone impressions of each template were made to create guides for consistent wire positioning (Figure 2). The diameter and, consequently, surface area of composite placed were controlled with the silicone guides. A 15-cm retainer wire was bonded on each acrylic block. When bonding Ortho-FlexTech, the wider surface was placed facing the acrylic base.

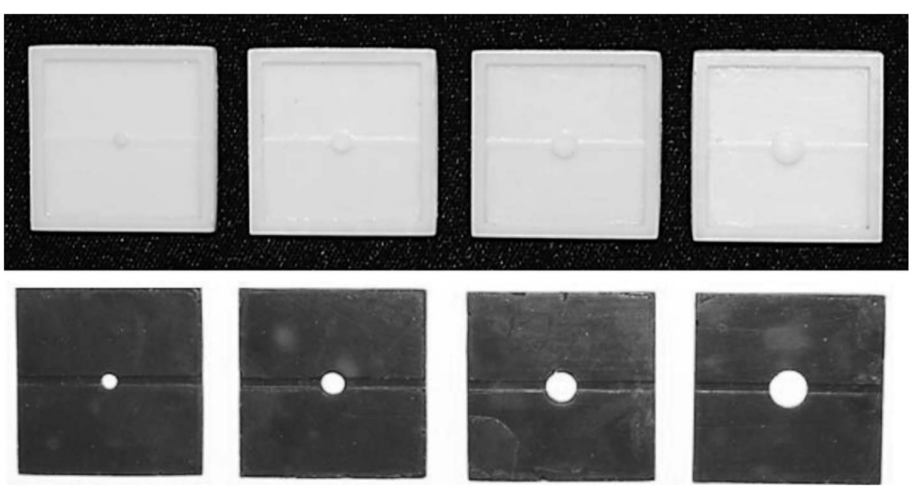

Figure 2. Three-dimensional–printed templates and the corresponding silicone guides with circular cutouts of varying diameters (2 mm, 3 mm, 4 mm, and 5 mm).

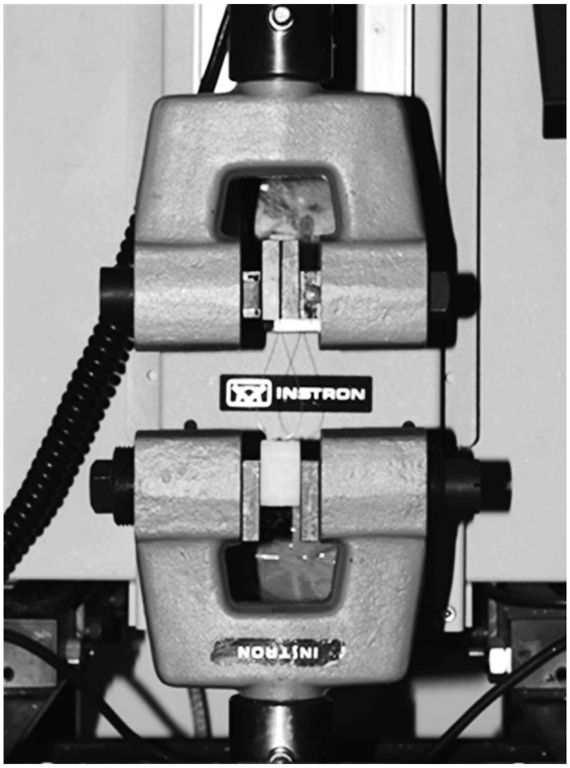

Figure 3. Experimental setup for tensile testing using an Instron machine.

A celluloid strip and clear flat load were placed on top of the composite before curing to ensure a smooth surface and elimination of excess material. The composite was light cured for 20 seconds, followed by another 10 seconds after removal of the silicone guide. This ensured complete curing of surfaces obscured by the opaque silicone material. At least 1 mm of acrylic was trimmed before bonding to ensure a fresh surface was used each time. The samples were tested to failure using an Instron machine in a tensile mode with 10 mm/min crosshead speed,[4] and the debonding force was recorded (Figure 3).

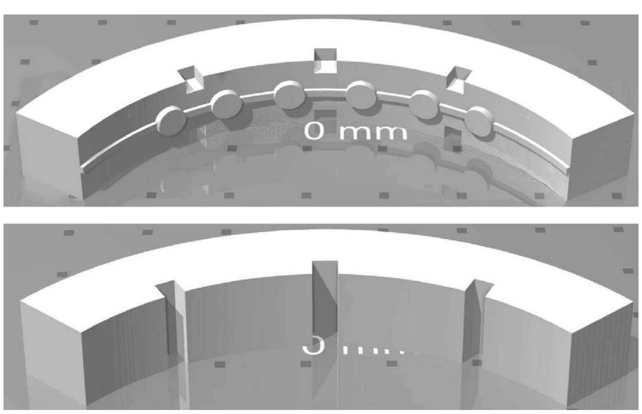

Figure 4. Three-dimensional–printed models. (Upper image) Experimental setup replicating a canine-to-canine retainer. (Lower image) Maxillary arch base for bonding of fixed retainer.

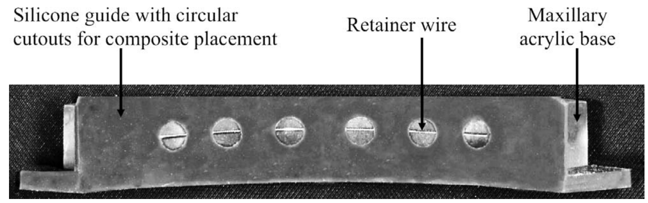

Figure 5. Sample preparation for study of force propagation along a retainer wire.

Using a 2 × 4 model, the two different retainer wires were subdivided based on composite surface diameters (2 mm, 3 mm, 4 mm, and 5 mm). A pilot study was conducted, and the resulting effect size (.297) and sample size were calculated with the G*Power 3.1.9.6 statistical program.[12] It was estimated that 150 samples were required to achieve 95% power and $P \leq .05$ significance. Therefore, 160 samples were prepared and divided equally into each subgroup (n = 20).

Force Propagation Within Fixed Retainers

A model replicating a maxillary canine-to-canine fixed retainer with 4-mm diameter composite pads was 3D-printed (Figure 4), and a medium-body silicone impression was made to fabricate a positioning guide. Notches in the design helped produce projections on the impression, which aided its seating within the corresponding notches on the acrylic bases used for retainer fabrication. The distance between bonding sites was predetermined according to the average mesiodistal width of the maxillary teeth.

A separate stereolithographic (STL) file resembling a maxillary arch was designed and 3D-printed (Figure 4). Putty impressions were made, and 72 copies of the model were fabricated by pouring cold-cure acrylic. A fixed retainer was bonded on the inner surface of each model using the previously fabricated silicone guide (Figure 5). Thirty-six models were bonded with Ortho-FlexTech and the remainder with Ortho-Care Perform. Each group was divided equally, with 18 samples subjected to loading between the two central incisors and another 18 loaded between the lateral incisor and canine.

Force was applied to the fixed retainers occluso-apically (Figure 6). Wire extension at first sign of failure was recorded and presented as deformation. A retainer was deemed to have failed if wire fracture, cracks, or complete debond of composite pads were observed. Ten samples in each subgroup were concurrently video recorded throughout force loading at 25 frames per second with full high definition quality. Individual video frames were extracted at 0.2-second intervals using VLC media player 3.0.8 (Free Software Foundation, Inc., Boston, Mass). Video frames at the start of force application and just before failure were compared

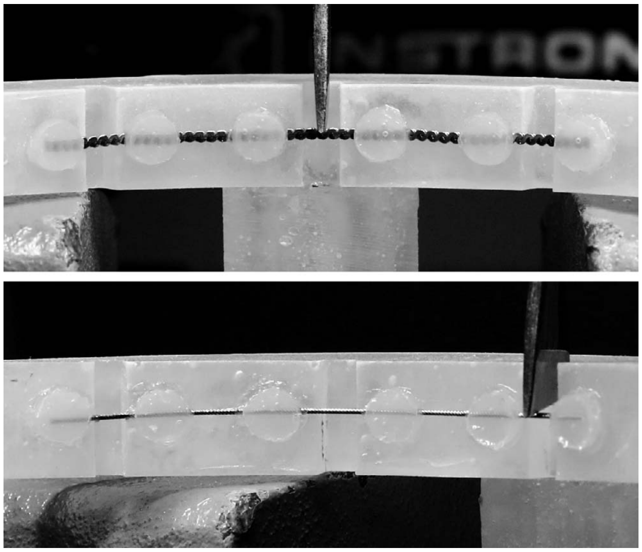

Figure 6. Experimental setups to assess force propagation along a fixed retainer.

pixel by pixel and their differences highlighted using Diffchecker, an online image comparison tool.

A scoring system was developed to quantify the force propagation observed along a retainer wire. Each composite pad and the underlying wire segment were scored between 0 and 4 based on the extent of differences highlighted (Table 1; Figure 7). Unsupported sections of wire not bonded with composite were not scored, even if highlighted, to eliminate differences due to ambient conditions. The total force propagation score for every sample was obtained by adding the score from each bonding site to reflect the evidence of distortion at all six possible locations. The highest total score possible for each sample was 24.

Table 1. Novel Force Propagation Index to Quantify the Difference Observed at the Start of Force Application and Just Before Retainer Failure

Score	Description
0	Highlighted areas only on: a. Margins of the composite and/or b. Minimal dots on composite body with none outlining segment of wire bonded with composite
1	Discontinuous speckled patterns on: a. Covered segment of retainer wire or b. Along the wire margins with the central region (body) of the wire remaining relatively clear of any dense highlighted patterns
2	Dense continuous extension of highlighted region covering less than half of the wire segment bonded with composite with/without additional highlighted areas on the composite body and margins
3	Dense continuous extension of highlighted region covering half/more than half of the wire segment bonded with composite with/without additional highlighted areas on the composite body and margins
4	Dense continuous extension of highlighted region covering entire length of wire segment bonded with composite

Statistical Analysis

Descriptive statistics including means and standard deviations were calculated. IBM SPSS Statistics for Windows, version 28 (IBM Corporation, Armonk, NY) was used for inferential statistical analysis. Levene's and Shapiro-Wilk tests confirmed the homogeneity of variances and normality of the tensile pull-out data. A two-way analysis of variance (ANOVA) was used to analyze the effect of each independent variable.

Three samples from each group of video recordings were selected through randomization software and

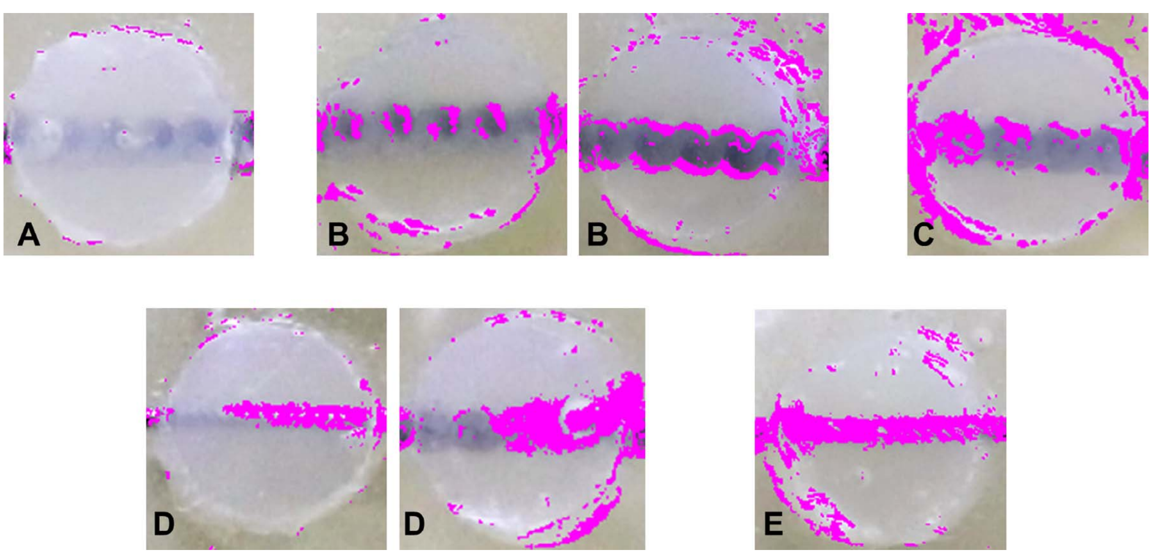

Figure 7. Examples of force propagation index scores. Score 0 (A), 1 (B), 2 (C), 3 (D), and 4 (E).

Table 2. Summary of Mean Debonding Force

Group					
Retainer Wire	Composite Surface Diameter, mm	n	Mean Debonding Force, N	Standard Deviation, N	Standard Error
Ortho-FlexTech (stainless steel)	2	20	14.13	6.49	1.45
	3	20	22.68	9.76	2.18
	4	20	33.02	13.95	3.12
	5	20	30.78	13.86	3.10
Ortho-Care Perform coaxial wire 0.0175 inches	2	20	18.94	9.16	2.05
	3	20	26.57	12.29	2.75
	4	20	30.42	12.65	2.83
	5	20	29.95	9.10	2.03

scored twice by the same assessor at a 2-week interval. Excellent intrarater reliability was observed, with an intraclass correlation coefficient of .993. Two-way ANOVA was carried out for the analysis of force propagation scores. As the data for wire extension at initial sign of failure did not fulfil the normality and homogeneity requirements for parametric testing, a Mann-Whitney *U* test was used. The significant threshold for all analyses was set at $P = .05$.

RESULTS

Effect of Varying Adhesive (Composite) Coverage on Retainer Failure

Ortho-FlexTech and Ortho-Care Perform recorded the highest mean debonding force when 4-mm-diameter composite pads were used (Table 2; Figure 8). Statistical difference was observed for varying composite surface diameters ($P < .001$), with the mean debonding force for 2 mm being significantly lower than that of other dimensions (3 mm, 4 mm, and 5 mm). Post hoc comparisons are shown in Table 3. There was no statistically significant difference in the debonding force between the two wires ($P = .457$).

Force Propagation Within Fixed Retainers

The average force propagation scores for Ortho-Care Perform, when loaded between the two central incisors and between a lateral incisor and canine, were 18.2 and 13.8, respectively. Conversely, Ortho-Flex-Tech produced average scores of 6.8 and 6.5 when loaded at similar locations (Figure 9). Two-way ANOVA showed that the mean difference of 9.35 between the wires was significantly different ($P < .001$; 95%

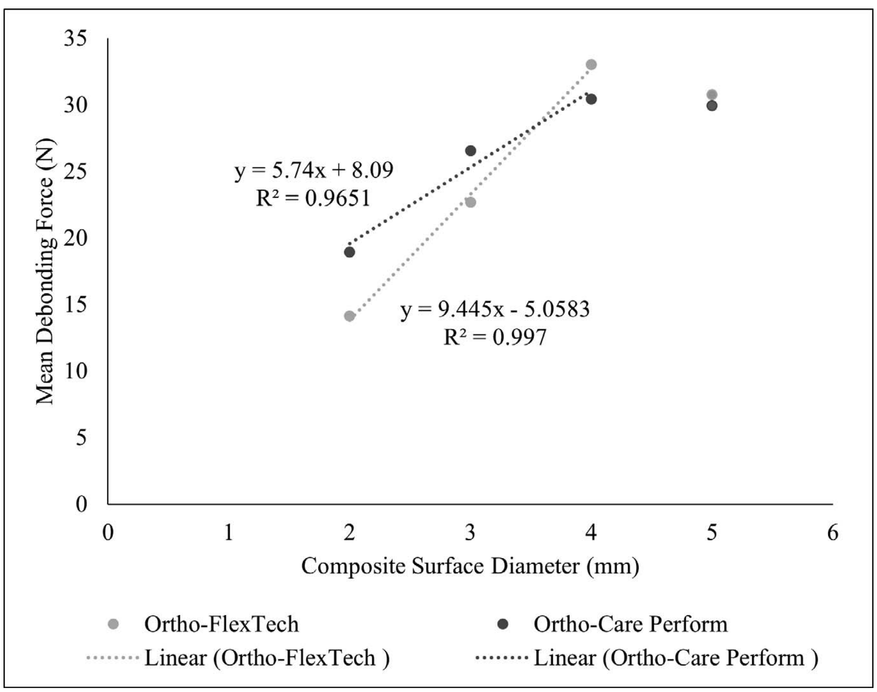

Figure 8. Scatter plot and trendline of mean debonding force (N) for different retainer wires at varying composite surface diameters (mm).

Table 3. Tukey Honest Significant Difference Post Hoc Comparison of Debonding Force for Different Composite Surface Diameters (Dependent Variable: Debonding Force)

Composite Surface Diameter, mm		Mean Difference, N (I–J)	Standard Error	Significance	95% Confidence Interval	
(I)	(J)				Lower Bound	Upper Bound
2	3	−8.09*	2.50	.008	−14.59	−1.59
	4	−15.19*	2.50	<.001	−21.69	−8.69
	5	−13.83*	2.50	<.001	−20.33	−7.33
3	2	8.09*	2.50	.008	1.59	14.59
	4	−7.10*	2.50	.026	−13.59	−0.60
	5	−5.74	2.50	.104	−12.24	0.76
4	2	15.19*	2.50	<.001	8.69	21.69
	3	7.10*	2.50	.026	0.60	13.59
	5	1.36	2.50	.949	−5.14	7.86
5	2	13.83*	2.50	<.001	7.33	20.33
	3	5.74	2.50	.104	−0.76	12.24
	4	−1.36	2.50	.949	−7.86	5.14

* Mean difference is significant at the .05 level.

confidence interval [CI]: 7.94, 10.77). Force propagation was significantly higher when loading was done between the two central incisors than between the lateral incisor and canine ($P = .002$; 95% CI: 0.94, 3.77).

Further analysis revealed that Ortho-FlexTech exhibited more extension when loaded at the center prior to failure. Nevertheless, the variation in deformation between different wires and loading locations was not statistically significant (Table 4). Similarly, one-way ANOVA testing on the mean load recorded at the first sign of failure revealed an insignificant difference, $P = .057$ (Table 5).

There was an almost equal number of wire fractures in both wires (Ortho-FlexTech = 6; Ortho-Care Perform = 5). Three samples had complete debond of at least one composite pad. Cracks and partial bond failure were observed in the remaining samples (Ortho-FlexTech = 28; Ortho-Care Perform = 30).

DISCUSSION

The Ortho-FlexTech wire used in the present study was of the stainless-steel variant with an interlocking chain design, measuring 0.0383 inches wide and 0.0158 inches in height. The Ortho-Care Perform stainless-steel wire had an overall diameter of 0.0175 inches and a coaxial design comprising five wires wrapped around a central core wire.

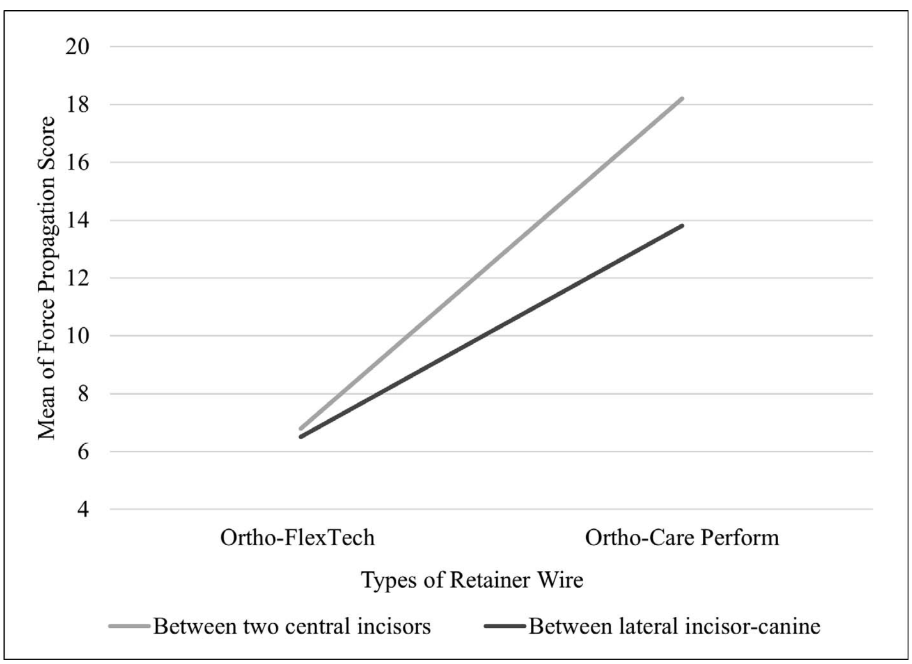

Figure 9. Line graph of mean force propagation score for different retainer wires and force loading positions.

Table 4. Median Values of Wire Extension Just Before Failure and the Corresponding Mann-Whitney *U* Comparisons

	Ortho-FlexTech		Ortho-Care Perform	
Position of Force Loading	Between the Central Incisors	Between the Lateral Incisor and Canine	Between the Central Incisors	Between the Lateral Incisor and Canine
Median, mm	2.37	1.66	1.78	1.68
Wire extension at failure (*P* values pairwise comparison)				
Ortho-FlexTech (force between the central incisors)	—	—	—	—
Ortho-FlexTech (force between the lateral incisor and canine)	0.068	—	—	—
Ortho-Care Perform (force between the central incisors)	0.091	0.563	—	—
Ortho-Care Perform (force between the lateral incisor and canine)	0.051	0.791	0.791	—

Effect of Varying Adhesive (Composite) Coverage on Retainer Failure

As the R^2 value for trendlines relating to 2-mm, 3-mm, and 4-mm coverage exceeded 0.9, their corresponding equations may be used to estimate the force necessary to promote retainer failure based on coverage ranging from 2 mm to 4 mm (Figure 8). The data appear to suggest that a minimum of 4-mm composite diameter should be used for bonded retainers in the maxillary intercanine region. Any value less than 4 mm may render the retainer of insufficient strength to resist debonding force, while a larger dimension does not seem to confer additional benefits.

The superior flexibility and increased surface area for bonding of a chain-like wire most probably enabled transfer of forces over a wider surface area, resulting in lower stress concentration at any single point of the composite-wire junction. This was seen in the improved resistance to debond of Ortho-FlexTech when 4-mm and 5-mm diameters composite pads were used. Similar findings were not observed with smaller diameters (2 mm and 3 mm) as the adhesive overlying a broader wire may have been insufficient to resist the propagated forces.

Overall, the debonding force recorded was lower than that reported by Bearn and co-workers,[4] most likely due to the different method of sample preparation. Bearn et al.[4] drilled a circular notch in an acrylic block and filled this with composite after seating the retainer wire. The composite base and curved surface were thus bonded to the surrounding acrylic. Conversely, only the composite base was bonded in the current study to replicate a clinical setup. The ensuing decrease in bonded composite surface area likely led to reduced resistance to pull out and failure at lower force levels.

Force Propagation Within Fixed Retainers

Experimental setup. Mandibular retainers routinely extend from canine to canine, while a range of bonding sites exists for maxillary retainers. This can be dependent on the original malocclusion, final occlusion, tooth morphology, oral hygiene maintenance, and clinician preference. Although maxillary retainers involving canines exhibited a higher propensity for failure, their ability to maintain alignment of the labial segment is generally regarded as superior to those bonded solely to incisors.[13,14] Therefore, the current study was conducted based on a canine-to-canine setup.

Four-millimeter composite pads were used, as they offered superior resistance to pull out. The limited dimensions of the Instron attachments available meant that only the mesiodistal widths of maxillary teeth were incorporated, ensuring sufficient distance between composite pads to permit consistent load application. Coupled with notches in the dental arch models, this helped minimize friction between the acrylic base and load attachment during mechanical testing.

Outcome. Force propagation scores for Ortho-Care Perform were significantly greater than for Ortho-FlexTech, reflecting more extensive load propagation through the multistranded coaxial wire. This contrasted with Engeler et al.,[15] who found that multistranded coaxial wires in general demonstrated less torsional load transfer than Ortho-FlexTech. They used a torsional bend to generate load transfer, whereas

Table 5. Mean Load at First Sign of Retainer Failure

					95% CI	
	n	Mean, N	SD	Standard Error	Lower Bound	Upper Bound
Ortho-FlexTech (force between the central incisors)	18	67.26	18.86	4.44	57.89	76.64
Ortho-FlexTech (force between the lateral incisor and canine)	18	66.62	24.91	5.87	54.23	79.01
Ortho-Care Perform (force between the central incisors)	18	69.45	17.01	4.01	60.98	77.91
Ortho-Care Perform (force between the lateral incisor and canine)	18	81.99	12.51	2.95	75.77	88.21

force was loaded occluso-apically at the unsupported intercomposite wire segment in the present study. In addition, six bonding sites mimicking a canine-to-canine retainer were used here instead of a two-teeth setup.[15] The findings were, however, comparable with the higher reactionary maximum force and moment reported by Sifikakis and coworkers[16] when they applied gradual intrusion force on a multistranded wire.

Arnold et al.[10] reported the stiffness of Ortho-FlexTech as the second lowest after Respond in their study involving seven commercially available retainer wires. This corresponded to the present results, in which wire deformation just before failure was highest for Ortho-FlexTech when loaded between the central incisors, indicating lower stiffness compared with the other setups.

Clinical Significance

An excessively rigid retainer may not only be more prone to failure but also potentially exert damaging forces on the periodontium, causing unwanted tooth movement postretention. Retainer rigidity can be influenced by the amount of composite applied and wire type. Where practical, composite coverage at each bonding site should be of at least 1-mm thickness[4] and 4-mm width in the maxillary intercanine region. Marginally wider coverage may, however, be considered clinically, as the composite applied typically resembles a dome with thinner margins to enhance patient comfort and plaque control and limit undercuts on the bonded surfaces.

The manufacturer of Ortho-FlexTech has advised that a secondary wire be used in cases with pretreatment spacing to avoid reopening of a diastema. Given the greater wire extension observed during loading, this suggestion appears to be valid. Although the resistance of Ortho-FlexTech to detachment was marginally better when sufficient composite was used, clinical failure was not confined solely to detachment or wire fracture. Wire activation resulting in unwanted tooth movement posttreatment is another form of failure. In this regard, Ortho-Care Perform, the more rigid of the two wires, may be susceptible to more stress in response to external forces. Given its coaxial design, the higher accumulated terminal load is likely to be converted into other forms of energy, one of which may be expressed as untwisting of the wire and transfer of undesirable forces to the bonded teeth. This would explain the previously reported development of the twist effect and buccal inclination of a mandibular canine.[6,9]

Conversely, a rectangular interlocking chain design is more resistant to twisting. Video recordings showed that none of the Ortho-FlexTech samples underwent a large amount of force propagation (scores 2, 3, and 4) beyond the composite pads immediately adjacent to the force origin. Based on this experiment, force applied is therefore not completely transmitted along the wire with energy likely dissipated as kinetic and thermal energy during plastic deformation. Ortho-FlexTech which has a larger surface area in contact with the overlying adhesive may lose a higher proportion of energy through friction at the wire composite interface. Intuitively, therefore, a retainer wire with greater inherent flexibility and wider surface area may lose more energy on deformation and consequently have less residual energy capable of causing unwanted tooth movement following release of force. This, however, does not discount the potential risk of unwanted torque changes being introduced by torsional forces transmitted along rectangular retainer wires.

Limitations

The study involved an in vitro setup replicating a clinical situation. While functional forces are often concurrently exerted on the dentition and exposed wire segments in a cyclic pattern, loading in the present experiment was applied continuously at a single point. As an acrylic model was used instead of natural teeth, the biological influence of the intraoral environment and periodontal ligament were accounted for.

In addition, the findings may not be representative of all retainer wires, as only two commercially available wires were tested. Specifically, for multistranded coaxial wires, the number of strands wrapped around the central core and overall dimensions can influence their physical properties.[10] Inclusion of fixed retainers made with a wider range of wire dimensions, designs, and materials, as well as utilization of measurement techniques with improved sensitivity, should be considered in future studies.

Similarly, the span between composite pads is likely to influence mechanical properties of a fixed retainer. Although 4-mm composite pads offered the best resistance to failure, this may not be true in the mandible, as reduced intercomposite distance may increase the rigidity of fixed retainers and their associated failure rate. In addition, the composite pads used clinically resemble a dome with thinner peripheries, while circular pads with uniform thickness were used here. Consequently, even if a similar width and thickness of composite is used, the amount of overlying composite supporting a retainer wire intraorally would be less than that used in the current study.

CONCLUSIONS

- Within the limitations of the experimental setup, 4-mm width of composite coverage per tooth should be used when bonding a fixed retainer in the maxillary intercanine region.

- More than 4 mm of coverage does not appear to offer appreciable benefit and may promote failure of retainers due to the increased stiffness, which resists physiologic mobility.
- A coaxial wire may be more prone to stress accumulation at its terminal ends, exerting unwanted forces during long-term fixed retention.
- Ortho-FlexTech may be susceptible to stretching prior to failure but risks less stress accumulation and associated force propagation over time.

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