Original Article

Mechanical properties and surface characterization of translucent composite wire following topical fluoride treatment

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ABSTRACT

Objective: To determine the effects of a fluoride prophylactic agent on the mechanical properties and surface quality of a preformed round translucent composite archwire while comparing it with nickel-titanium (Ni-Ti) and multistranded stainless steel wires.

Materials and Methods: The wires were immersed in an acidulated phosphate fluoride solution (APF) or in distilled water (control) for 1.5 hours at 37°C. Flexural modulus of elasticity (E) and yield strength (YS) of the wires were measured using a three-point bending test in a universal testing machine. The springback ratio (YS/E) was calculated for each wire. The influence of fluoride treatment on properties of the wires was statistically analyzed using Student's *t*-test at $\alpha = .05$. Surface changes were observed with a scanning electron microscope.

Results: Fluoride treatment produced a statistically significant reduction in E, YS, and YS/E of the composite wire ($P < .05$). In addition, a significant decrease in E of Ni-Ti wire was found after exposure to fluoride, upon comparison with distilled water control treatment. On the other hand, no significant effect of fluoride treatment was found on YS and YS/E of Ni-Ti wire and on studied properties of the multistranded stainless steel wire ($P > .05$). Corrosive changes in surface topography were observed after exposure to the fluoride agent and were more pronounced with the composite wire.

Conclusions: These results suggest that using a topical fluoride agent with translucent composite wire could decrease the mechanical properties and might damage the surface of the wire, potentially contributing to prolonged orthodontic treatment. (*Angle Orthod.* 2012;82:8–13.)

KEY WORDS: Translucent wires; Initial archwires; Springback; Fluoride

INTRODUCTION

The direct bonding system has been considered one of the most significant developments in clinical orthodontics. Today, multibracket appliances are widely used, and better mechanical properties of these appliances have been emphasized. Orthodontic brackets are usually made of stainless steel. However, the quality of plastic or ceramic brackets has been improved recently, and the use of such esthetic brackets is becoming more popular. Many studies have been carried out on these esthetic brackets with a plan to improve their mechanical properties.[1–3]

The archwire, which is one of the main parts of a multibracket appliance, is designed to move teeth from malocclusion to a preferred dental occlusion through mechanical interaction with the bracket slots. Dental arch alignment and leveling constitute the initial stage of orthodontic treatment. Satisfactory completion of this stage is essential if esthetics, function, and stability are to be achieved. Ideally, in this vital stage, the wire should generate a continuous light force over a prolonged period of time.[4,5] Knowledge of the mechanical properties of such wires is very helpful to the clinician in the design and application of optimal force systems during orthodontic treatment.[6] Although the type of wire most frequently recommended for this first stage is superelastic nickel titanium (Ni-Ti), some technicians prefer multistranded stainless steel archwires because they are cheaper and are as clinically effective as Ni-Ti wires.[4,5,7]

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With the steady increase in the number of adults undergoing orthodontic treatment has come a demand for more esthetic orthodontic appliances.[8] The development of orthodontic appliances and materials with acceptable esthetics for the patient and optimal technical performance for the orthodontist has been an extremely essential goal.[9] Two kinds of archwire have been produced to improve esthetics. One is a metal wire with white Teflon (polytetrafluoroethylene) or epoxy resin on the surface. The other type is made from translucent composite materials using a polymer for the matrix and glass fibers for reinforcement.[10] It has been suggested that these wires not only are high in esthetics but also have mechanical properties similar to those of metal wires.[11] A recent introduction into the market, the BioMers translucent archwire, has been developed especially as an initial leveling and aligning wire. This wire is manufactured by a patented polymer composite fabrication process. It comprises glass fibers as reinforcement and a polymer resin as the matrix. The glass fibers provide the necessary stiffness to straighten teeth, and the translucent polymer resin ensures that the wire is not clearly visible when in use. Together with the flexibility of the fabrication technology, wires of differing strength and stiffness can be engineered by varying the reinforcement level without compromising functionality. Fiber-reinforced composites are regarded as the last great frontier of orthodontic materials.

One of the most important components of successful orthodontic treatment is the maintenance of good oral hygiene and caries control. Compromised oral hygiene can lead to enamel demineralization and decay.[12,13] Daily topical fluoride is commonly prescribed by orthodontists to guard against this complication.[14] Acidulated phosphate fluorides (APFs) have been used extensively to prevent demineralization or remineralization of white spot lesions around orthodontic brackets. However, fluoride ions in the prophylactic agents have been reported to cause corrosion, discoloration and alteration of the mechanical properties of metallic wires, particularly when passivated wire surfaces break because of mechanical friction between brackets and wires.[15,16] To date, the effects of prophylactic fluoride agents on the mechanical properties of translucent composite archwire have not been reported. The purpose of this study was to evaluate the effects of a fluoride prophylactic agent on the mechanical properties and surface topography of a translucent composite wire compared with Ni-Ti and multistranded stainless steel wires.

MATERIALS AND METHODS

Three types of commercially available round orthodontic archwires were investigated in this study. These wires included a preformed translucent composite (Translucent Archwire, BioMers Products LLC, Naples, Fla), Ni-Ti (Super Elastic NiTi, International Orthodontic Services Inc, Houston, Tex), and multistranded stainless steel (Tricat, Dentsply GAC International, Bohemia, NY). A full description of these wires is presented in Table 1. Each wire specimen was 0.016 inches in diameter × 25 mm in length, cut from the straight portion of preformed archwires. Twenty specimens were cut from each type of wire for a total of 60 specimens. For each type of wire, 10 specimens were incubated at 37°C in distilled water (control treatment), and the other 10 were incubated in a prepared fluoride solution (1.1% APF, 0.5% w/v fluoride, pH = 5.1) for 1.5 hours.[17]

Before testing, the specimens were removed from the respective solutions and were rinsed with distilled water. The diameter of all wires was determined with an electronic caliper (Mitutoyo, Tokyo, Japan) to an accuracy of 0.001 mm. All specimens were subjected to a three-point bending test, as described by Miura et al.[5] and modified by Krishnan and Kumar,[18] on a universal testing machine (Model LRX-Plus, Lloyd Instruments Ltd, Fareham, UK) with a load cell of 5 kN. The setup included a specially constructed fixture comprising two poles placed 12 mm apart on a stage attached to the lower jaw of the machine. Compressive force was applied at a crosshead speed of 0.5 mm/min by means of a steel rod with a bibeveled chisel end placed midway between the two poles. Each specimen was loaded to a deflection of 3.1 mm. Load in newtons and deflection in millimeters were recorded for each specimen with a computer software

Table 1. Orthodontic Wires Used in the Study[a]

Wire	Wire Size and Brand	Composition	Manufacturer	Batch #
Translucent composite	0.016 in translucent archwire	Mixture of cured copolymers, Bis-EMA, TEGDMA, and glass fibers	BioMers Products LLC, Naples, Fla	080919
Nickel-titanium	0.016 in superelastic Ni-Ti wire	52% Ni, 45% Ti, and 3% Co	International Orthodontic Services Inc, Houston, Tex	067392
Multistranded stainless steel	0.016 in Tricat wire	71% Fe, 17%–20% Cr, 8%–12% Ni, and 0.15 C	Dentsply GAC International, Bohemia, NY	0301633

[a] Bis-EMA indicates ethoxylated bisphenol A glycol dimethacrylate; TEGDMA, triethylene glycol dimethacrylate.

Table 2. Mean Values, Standard Deviations, and Results of *t*-Tests of Mechanical Properties of the Studied Wires After Exposure to Distilled Water or Fluoride Solution

Wire	Treatment	Mean Flexural Modulus of Elasticity, GPa ± SD	Mean Yield Strength, MPa ± SD	Springback Ratio, 10^{-3} ± SD
Translucent composite	Distilled water (control)	37.5 ± 2.0	594.9 ± 17.0	15.9 ± 0.7
	Fluoride	34.7 ± 2.4*	504.4 ± 15.8*	14.6 ± 1.2*
		t = 3.045	t = 12.430	t = 2.862
		P = .014	P = .0001	P = .019
Nickel-titanium	Distilled water (control)	68.2 ± 3.5	1007.1 ± 37.5	15.1 ± 1.1
	Fluoride	63.1 ± 6.5*	990.7 ± 47.2	15.9 ± 2.0
		t = 3.160	t = 1.052	t = 1.029
		P = .012	P = .320	P = .330
Multistranded stainless steel	Distilled water (control)	105.8 ± 7.3	1092.0 ± 26.2	10.4 ± 0.8
	Fluoride	104.2 ± 7.7	1082.9 ± 28.5	10.3 ± 0.9
		t = 0.665	t = 1.792	t = 0.314
		P = .522	P = .107	P = .761

* Significantly different from control ($P < .05$).

program (Nexygen-MT, Lloyd Instruments Ltd). Based on the load-deflection curve and the dimensions of the specimen, flexural stress as a function of flexural strain was determined for each specimen. Flexural modulus of elasticity (E) and yield strength (YS) were calculated for each specimen. Springback ratio (YS/E) was calculated for each specimen by dividing yield strength by modulus of elasticity. The influence of fluoride treatment on properties of the wires was statistically analyzed using Student's *t*-test at $\alpha = .05$. Statistical calculations were performed using the Statistical Package for the Social Sciences (SPSS) software program, version 17 (SPSS Inc, Chicago, Ill).

One representative wire was randomly selected from each wire/experimental condition for scanning electron microscope (SEM) analysis to characterize the topography of the wire surface. After gold coating of the translucent composite wire, the specimens were mounted with double-sided conductive carbon tape and carbon paint on aluminum SEM stubs and were examined using an SEM (Philips XL3-Philips, North Billerica, Mass) at 1000× magnification.

RESULTS

Mean elastic modulus, yield strength, springback ratio, standard deviations, and results of *t*-tests of the studied wires after immersion in distilled water and APF solution are presented in Table 2. A graphical presentation of the results of the springback ratio is shown in Figure 1. Fluoride treatment produced a statistically significant decrease in E, YS, and YS/E of the composite wire, upon comparison with distilled water control treatment ($P < .05$). In addition, fluoride treatment produced a significant reduction in the E of Ni-Ti wire. On the other hand, no significant effect of fluoride treatment was found on YS and YS/E of Ni-Ti wire ($P > .05$). In addition, fluoride treatment had no significant effect on studied properties of the multistranded stainless steel wire ($P > .05$).

Representative scanning electron photomicrographs of the studied wires exposed to distilled water and APF solution are shown in Figure 2. Observations indicated that some surface changes occurred on the surfaces of wires after immersion in APF agent. In particular, composite wire demonstrated dramatic changes in surface morphology. In distilled water treatment, the wire surface appears homogeneous with few irregularities. In contrast, fluoride treatment produced an inhomogeneous surface with more irregularities and some surface damage, suggesting loss of surface material. SEM images of Ni-Ti wire exposed to distilled water showed some dark areas, which might be byproducts of the manufacturing process. After fluoride treatment, the surface had a mottled, slightly pitted appearance with some bright-white spots, which may result from the action of fluoride. As compared with the distilled water control wire, following exposure to AFP, stainless steel wire surface appeared rougher and the cracks along the wrought structure were more prevalent and more accentuated, indicating some surface corrosive effects.

DISCUSSION

One of the disadvantages of direct bonding is that enamel demineralization can occur around orthodontic brackets. Because fluoride enhances the potential for remineralization, use of topical fluoride preparations during orthodontic treatment has been advocated.[19,20] In vitro studies[15,17] have reported the deleterious effects of fluoride agents on the mechanical properties of metallic orthodontic wire. Currently, fiber-reinforced polymer composites are being developed for use as orthodontic archwire materials. These wires can be

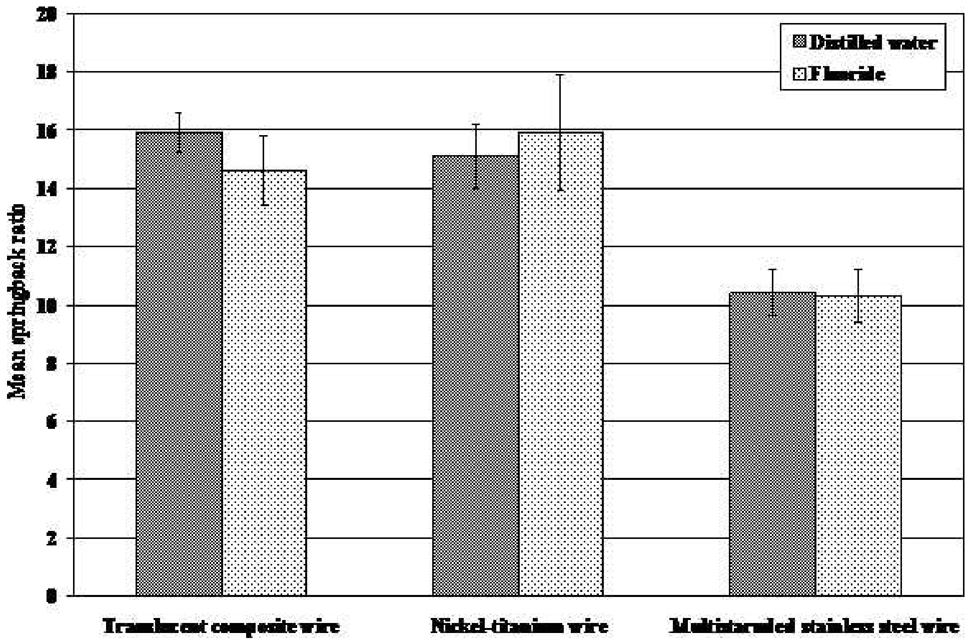

Figure 1. Mean springback ratio (YS/E) and standard deviations of the studied wires after immersion in distilled water and fluoride solution.

manufactured in a wide range of clinically relevant levels of elasticity, allowing practitioners to use variable-modulus orthodontic techniques without having to change the archwire. Allergic reactions to nickel, which are a debatable concern for many metallic alloys, are also averted with composite materials. The current in vitro study evaluated the effects of fluoride treatment on the mechanical properties and surface quality of a translucent fiber–reinforced composite wire by comparing it with the most frequently used archwires for the first stage of orthodontic treatment. The wires were exposed to distilled water and APF solution for 1.5 hours. This exposure time would be equivalent to 3 months of 1-minute daily topical fluoride applications, as stated by Walker et al.[17] in 2005. E and YS were determined for each wire. The ratio YS/E is considered to be a very useful index of wire performance.[21] This ratio indicates the clinical performance of the wire in terms of load-deflection rate, working range, stiffness, and resilience.

The findings of the present study indicate that fluoride treatment produced a statistically significant decrease in E, YS, and YS/E of the composite wire. This could be attributed to the deteriorating effect of acidic fluoride on the glass filler present in the composite wire. This was consistent with what has been observed on SEM images (Figure 2) showing damage to the surface of the wire after exposure to fluoride solution. This observation matches the results of previous studies, which also found that topical application of APF gels might damage surfaces of composites with glass filler particles.[22,23] In addition, acidic fluoride regimens, such as APF, may lead to increased surface roughness of resin composite materials.[24] It has been found that glass particles are more prone to stress corrosion when exposed to media of high or low pH, whereas pure silica fillers are less affected by acidic media.[25] In addition to this direct influence of acidic media on fillers, fluoride may cause depolymerization of the matrix-filler interface and support filler loss from the matrix, as reported by Bowen and Cleek.[26]

Results of the present study show a significant decrease in the flexural modulus of Ni-Ti wire after fluoride treatment compared with distilled water control treatment. This is probably a result of the corrosive effect of topical fluoride on titanium-based orthodontic wires. These findings are consistent with the results of previous studies, which suggested that fluoride adversely affects the mechanical properties of Ni-Ti wires.[17,27] Degradation and loss of oxide film on the surface expose the underlying alloy, leading to corrosion and absorption of hydrogen ions from the aqueous-based solution as a result of the high affinity of titanium with hydrogen.[28] Hydrogen absorption and associated embrittlement of titanium-based alloys have been explained by the diffusion of hydrogen through interstitial sites, dislocations, and grain boundaries reacting with lattice atoms to form hydride phases, particularly titanium hydride. Titanium hydrides have been reported to form a body-centered tetragonal structure, considered to be the cause of related degradation of mechanical properties of the alloy.[29]

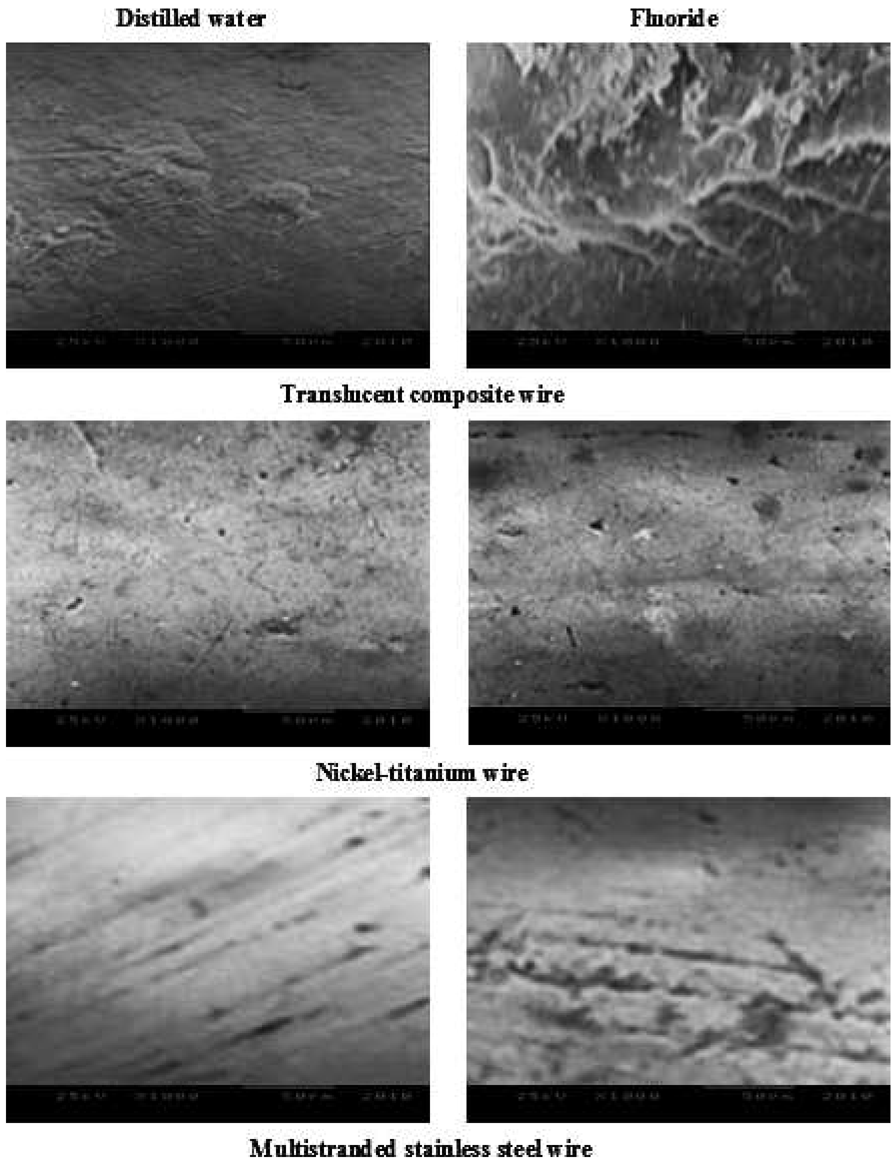

Figure 2. Representative SEM images of translucent composite, nickel-titanium, and multistranded stainless steel wires exposed to distilled water and fluoride solution (1000× magnification).

In comparison with the studied wires, the apparent lack of fluoride effect on the mechanical properties of multistranded stainless steel wire could be related to its elemental composition whereby chromium and nickel impart corrosion resistance. Chromium contributes to the surface oxide layer, which spontaneously undergoes passivation and repassivation in air and the oral environment. Nickel aids corrosion resistance by competing with chromium to form salts, making more chromium available for passivation. These findings coincide with the results of a previous study, which found that stainless steel is less susceptible to corrosion in a fluoridated acidic environment when compared with Ni-Ti.[30] In addition, multistranded stainless steel wires are composed of a specified number of thin wire sections coiled around each other. This could be another contributing factor, regardless of the corrosive changes seen on SEM images (Figure 2).

Results of the present in vitro study demonstrate the deleterious effects of fluoride agents on the mechanical properties of translucent composite wire. However, these wires were exposed to fluoride agent continuously for 1.5 hours. In clinical situations, fluoride exposure would consist of repeated shorter exposures rather than continuous exposure. Therefore, a future study is needed to investigate the effects of cumulative fluoride exposure based on shorter, repeated treatments on the mechanical properties of orthodontic wires.

CONCLUSIONS

- Topical fluoride agent significantly decreased the mechanical properties of the translucent composite wire and might damage the surface of the wire, which potentially would contribute to prolonged orthodontic treatment.
- Nickel-titanium wire showed a significant decrease in the flexural modulus of elasticity after exposure to fluoride solution. In contrast, fluoride had no significant effect on the mechanical properties of multistranded stainless steel wire.

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