A CLINICAL TRIAL TO EVALUATE THE EFFECTS OF PROPHYLACTIC FLUORIDE AGENTS ON THE SUPERELASTIC PROPERTIES OF NICKEL-TITANIUM WIRES

**Aim:** To study the effects of a prophylactic fluoride regimen on the mechanical properties of nickel-titanium (Ni-Ti) archwires under clinical conditions. **Method:** The unloading properties of 100 Ni-Ti wires were tested using a three-point bending test at five deflections (0.5 mm, 1.0 mm, 2.0 mm, 3.0 mm, and 3.1 mm). Sixty-six 0.016 × 0.022-inch Ni-Ti wires were tested after being used intraorally for 6 weeks using two protocols. Thirty-three wires were evaluated after the use of fluoride-containing Crest toothpaste (sodium fluoride 0.243%, 0.15% w/v fluoride ion) and Equate fluoride rinse (sodium fluoride 0.05%, fluoride ion 0.0226%). Another 33 wires were examined after a nonfluoridated natural toothpaste (Tom’s of Maine; calcium carbonate, xylitol, myrrh, propolis, sodium lauryl sulfate, carrageenan, spearmint and peppermint oils, glycerin, and water) was used. Another 34 Ni-Ti wires served as a control; they were tested as received. Statistical analyses were carried out with a linear-mixed model (analysis of variance [ANOVA]). **Results:** Force degradation occurred within both groups of intraorally used wires but not in the unused archwires. When compared to unexposed wires, those with fluoride exposure exhibited slightly higher force degradation at 3.1 and 3.0 mm deflection, but they displayed less force degradation at 0.5 and 1.0 mm deflection. **Conclusions:** Topical fluoride regimens decreased the unloading property of Ni-Ti wires at higher deflections but increased it at lower deflections. World J Orthod 2010;11:135–141.

**Key words:** fluoride, nickel-titanium wires

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Some of the greatest developments in orthodontics can arguably be seen in straightwire and preadjusted appliances, bonding, and highly resilient wires. The efficacy of self-ligating brackets is controversial, and more evidence is needed to make a final determination.\(^1\)-\(^4\) Certainly, superelastic titanium wires have made orthodontic treatments faster and more efficient than traditional wires. Understanding and evaluating the properties of wires is important when orthodontists have to select the most appropriate archwire for a given clinical situation.\(^5\)-\(^8\)

The most popular wires include stainless steel, nickel-titanium (Ni-Ti), copper nickel-titanium (CuNi-Ti), and beta titanium. Archwire properties can be affected by various functional and oral environmental factors. These include (but are not limited to) masticatory forces, type of food ingested, intraoral pH, and, for the purpose of this study, fluoride. Ni-Ti wires are able to deliver a constant force because of their superelasticity and shape memory.\(^9\) The transformation of the crystal structure from austenite to martensite (ie, the passage from a cubic
lattice structure through a rhomboidal phase to a hexagonal close-packed lattice structure), due to a temperature change or the application or removal of stress, accounts for these characteristics. When the wire is unloaded and deactivated, it transforms back to its original austenitic structure. This reversion generates force and therefore orthodontic tooth movement.

Ni-Ti alloys are generally resistant to corrosion due to the formation of a thin oxide layer through passivation. Nonetheless, it has been reported that this layer can be chemically disrupted by various entities (including chloride, artificial saliva, sliding friction, and fluoride), leading to an increased risk of corrosion. The effects of many of these entities on both tensile strength and microhardness have been addressed in a study by Asgharnia and Brantley.

Orthodontists routinely use systemic and topical fluorides as a proactive, supportive adjunct to improve patients’ oral health. However, fluoride agents can cause both Ni-Ti and CuNi-Ti wires to discolor and corrode. They can also affect the mechanical properties of Ni-Ti, though not of CuNi-Ti wires. This was shown by Walker et al, who placed 10 Ni-Ti and 10 CuNi-Ti wires in a bath containing 2 mL each of Phos-fur gel (Colgate), Prevident solution (equivalent to 3 months of 1-minute application per day), and distilled, deionized water for 1.5 hours at 37°C. Because fluoride does not affect the mechanical properties of CuNi-Ti, even though it changes their surface configuration, it is assumed that there is no direct link between such changes and any mechanical properties. Nontheless, the corrosive effect of fluoride is believed to cause a loss of the protective oxide film exposing the underlying titanium alloy to hydrogen absorption and embrittlement (ie, oxidative reduction).

Titanium and hydrogen have a high binding affinity and form titanium hydride, which degrades the alloy’s mechanical properties by way of a body-centered tetragonal structure. The copper component of CuNi-Ti wires apparently protects the alloy against subsequent hydrogen penetration. At least in vitro, fluoride gels can negatively affect the unloading of Ni-Ti wires, which could contribute to less efficient, prolonged orthodontic tooth movements. Parenthetically, Walker et al recently also demonstrated a negative effect of fluoride on stainless steel and beta titanium wires in vitro.

There are many reports that have evaluated the mechanical properties of superelastic titanium archwires. However, there are no in vivo studies that have quantified the effect of fluoride agents on such wires. Thus, the purpose of this investigation was to evaluate this effect on the unloading properties of Ni-Ti archwires.

METHODS AND MATERIALS

Seventeen patients undergoing orthodontic treatment (aged 11 to 30 years) at the School of Orthodontics at Jacksonville University participated in this prospective clinical trial after approval from the university's Institutional Review Board. The ethical dilemma the study faced was the cessation of fluoride application in all patients for 6 weeks. Hence, excellent oral hygiene was a requirement for participation.

For leveling and aligning, the patients initially received a 0.018-inch Ni-Ti archwire (G & H Wire) for 6 weeks. These wires were not used in this study. The logic to use them before 0.016-inch Ni-Ti test wires were placed was to minimize any adverse effect on the properties of these wires due to too great an initial stress. The composition of the Ni-Ti wires of this study was 50% titanium, 49% nickel, and 1% other metals. The reasons for choosing 0.016 × 0.022-inch wires were that they are intermediate archwires between the initial flexible and the stiff finishing stainless steel wires and that this is a commonly used size.

After the wires were inserted, a 6-week fluoride regimen was initiated. The respective agents were Crest anticavity fluoride toothpaste (Procter & Gamble; sodium fluoride 0.243%, 0.15% w/v fluoride ion) and Equate fluoride rinse (Wal-mart; sodium fluoride 0.05%, fluoride ion 0.0226%). These products were chosen
because they are popular, readily available, inexpensive, and often prescribed. All patients were instructed to use them to the manufacturer’s instructions—brush and rinse twice daily. Patients were further informed that it was extremely important to follow these instructions; at each appointment, they were queried to ensure maximum cooperation. After 6 weeks, 33 wires (17 maxillary and 16 mandibular) were removed and lab tested; one wire was accidentally cut too short prior to testing.

New 0.016 \times 0.022\text{-}inch Ni-Ti archwires were placed in the same individuals for an additional 6 weeks. All patients were then instructed to use a nonfluoridated toothpaste (Tom’s of Maine natural toothpaste; calcium carbonate, xylitol, myrrh, propolis, sodium lauryl sulfate, carrageenan, spearmint and peppermint oils, glycerin, and water). The common protocol was to brush twice a day with this toothpaste and rinse twice daily with tap water. To match the number of the first trial, one wire was discarded so that 33 wires remained for lab testing.

Thirty-four unused archwires (17 maxillary and 17 mandibular) of the same dimension served as controls (in vitro study). No attempt was made to control background fluoride (fluoride from food or drinks) during this study. Because the same 17 individuals were employed for both study phases, the very same background fluoride was assumed to be present during both test phases. In addition, the wires were not separated into maxillary or mandibular ones. All wires were chosen randomly from the same batch.

Lab tests

Mechanical testing was based on the American National Standard/American Dental Association Specification no. 32 (Orthodontic Wires; American Dental Association, 2000). As per the Walker et al study,\textsuperscript{9} all specimens were tested with a three-point bending test on an universal testing machine (serial number 32168, MTS Insight 1 Material Testing System) in a water bath at 37°C. This testing was performed over the wide (0.022-inch) and small (0.016-inch) side of the wires. The configuration of the three-point fixture was a support span of 12 mm each—a 0.05- to 0.130-mm radii and a striker. Each specimen was deflected up to 3.1 mm and then unloaded to zero deflection at a crosshead speed of 1 mm/min. Force, in Newtons (N), and deflection, in millimeters (mm), were collected every 100 ms for both loading and unloading by using Testwork 4.9 software, which also generated respective load-deflection curves. After the testing machine was calibrated, each wire was loaded onto the brass fixtures under the load cell and its chisel was manually positioned as close to the wire as possible without contacting it. Data for all wires were generated at 0.5 mm, 1.0 mm, 2.0 mm 3.0 mm, and 3.1 mm extensions.

STATISTICAL METHODS

A total of 100 wires were tested (34 controls, 66 test wires [33 each with and without fluoride exposure]). All analyses were carried out using analysis of variance (ANOVA). Within the experiment, modality (fluoride/no fluoride exposure) and deflection (0.5 mm, 1.0 mm, 2.0 mm, 3.0 mm, and 3.1 mm) were treated as repeated measures. Fluoride exposed, fluoride not exposed, and control wires were treated as independent groups. For repeated measures analyses, compound symmetry was specified for the residual covariance structure. This decision was made on the basis of a visual inspection of the residual covariance matrix and the results from several commonly used goodness-of-fit tests (for example, –2 log likelihood and Akaike information criterion).

RESULTS

Table 1 summarizes the means, standard deviations, and medians of the observed load at the five deflections for the two wire diameters and all three wires. The null hypothesis that intraoral use had no effect on the mechanical properties of these Ni-Ti wires was rejected. The control
wires significantly outperformed the fluoride exposed wires in both dimensions and at all deflections (Tables 1 to 3). The nonfluoride exposed (intraoral) wires performed better than those under fluoride exposure at 3.0 mm deflection, almost equivalent at 3.1 mm deflection, and equivalent at 2.0 mm deflection. At 1.0 mm and 0.5 mm deflection, the fluoride exposed wires performed better than the nonfluoride exposed wires. Table 2 also indicates that there was no significant difference between the recovery loads for nonfluoride exposed and control wires for 3.1 mm and 3.0 mm deflection. Below these reflections, the control wires showed a significantly higher recovery. At the two smallest deflections, the nonfluoride exposed wires gave significantly worse results than both the control wires and the fluoride exposed ones. The large standard deviations for 0.5 mm and 1.0 mm deflection suggest that the differences between the fluoride- and nonfluoride-exposed wires may be insignificant in spite of the statistical significance.

Table 3 provides data on the changes that occurred between the individual deflections. From 3.1 mm to 2.0 mm, all three wires showed a significant decline in recovery for both diameters. At 1.0 mm and 0.5 mm, both intraoral wires tended to flatten out, showing only marginal differences. Although the statistical tests demonstrate a significantly different performance for the control wires (due to their very small standard error), they too demonstrated a marked flattening effect. The coefficient of variation was markedly increased when the wires were not exposed to fluoride (Fig 1). In contrast, it remained essentially constant for the control wire at all five deflections and across both diameters.

Figures 2 and 3 show the mean recovery load for the three treatment conditions (fluoride, nonfluoride exposed, and as received) for the 0.016- and 0.022-inch diameters.

| Table 1 | Means, standard deviations (SD), and medians of the recovery load (grams) at the various deflections, and wires and wire dimensions |
|----------------|----------------------------------|----------------|----------------|----------------|----------------|----------------|
|               | 0.016-inch                      |                | 0.022-inch                      |                |                |                |
|               | n  | Mean  | SD   | Median | n  | Mean  | SD   | Median | n  | Mean  | SD   | Median | n  | Mean  | SD   | Median |
| 3.1 mm        |    |       |      |        |    |       |      |        |    |       |      |        |    |       |      |        |
| Control       | 34 | 383.0 | 7.8  | 382.0  | 563.7 | 17.4  | 572.4 |       | 33 | 369.9 | 14.4 | 369.6  | 553.4 | 22.9  | 554.4 |       |
| Fluoride      | 33 | 385.7 | 42.9 | 374.7  | 574.0 | 73.9  | 557.9 |       | 33 | 302.1 | 42.4 | 292.65 | 444.4 | 65.1  | 430.2 |       |
| Nonfluoride   | 33 | 299.7 | 8.9  | 302.2  | 436.0 | 16.8  | 444.4 |       | 33 | 278.7 | 13.2 | 276.4  | 412.5 | 19.2  | 412.5 |       |

2.0 mm

| Control       | 34 | 221.4 | 6.8  | 222.5  | 311.1 | 9.3   | 316.3 |       | 33 | 201.7 | 18.1 | 202.3  | 282.8 | 22.2  | 278.6 |       |
| Fluoride      | 33 | 204.5 | 45.1 | 205.1  | 268.2 | 85.2  | 285.1 |       | 33 | 189.8 | 18.5 | 186.9  | 244.5 | 67.7  | 259.7 |       |
| Nonfluoride   | 33 | 118.3 | 88.5 | 173.6  | 135.5 | 129.6 | 159.7 |       | 33 | 103.3 | 98.4 | 130.1  | 108.3 | 113.9 | 28.2  |       |

1.0 mm

| Control       | 34 | 205.6 | 5.4  | 205.0  | 281.0 | 5.4   | 284.2 |       | 33 | 189.8 | 18.5 | 186.9  | 244.5 | 67.7  | 259.7 |       |
| Fluoride      | 33 | 190.8 | 38.1 | 199.5  | 207.7 | 78.0  | 234.8 |       | 33 | 103.3 | 98.4 | 130.1  | 108.3 | 113.9 | 28.2  |       |
| Nonfluoride   | 33 | 118.3 | 88.5 | 173.6  | 135.5 | 129.6 | 159.7 |       | 33 | 103.3 | 98.4 | 130.1  | 108.3 | 113.9 | 28.2  |       |

0.5 mm

| Control       | 34 | 211.3 | 4.5  | 210.3  | 252.7 | 9.6   | 255.3 |       | 33 | 190.8 | 38.1 | 199.5  | 207.7 | 78.0  | 234.8 |       |
| Fluoride      | 33 | 103.3 | 98.4 | 130.1  | 108.3 | 113.9 | 28.2  |       | 33 | 103.3 | 98.4 | 130.1  | 108.3 | 113.9 | 28.2  |       |
| Nonfluoride   | 33 | 103.3 | 98.4 | 130.1  | 108.3 | 113.9 | 28.2  |       | 33 | 103.3 | 98.4 | 130.1  | 108.3 | 113.9 | 28.2  |       |

n = number of wires studied.
Table 2  P values for the comparison of the mean recovery loads at the various deflections for the
different wires (as received [control], with [fluoride], and without fluoride exposure [nonfluoride]) and
both wire dimensions

<table>
<thead>
<tr>
<th>Wire diameter/group</th>
<th>Deflection (mm)</th>
<th>3.1</th>
<th>3.0</th>
<th>2.0</th>
<th>1.0</th>
<th>0.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.016-inch</td>
<td>Fluoride vs nonfluoride</td>
<td>.045</td>
<td>.003</td>
<td>.716</td>
<td>&lt; .001</td>
<td>&lt; .001</td>
</tr>
<tr>
<td></td>
<td>Fluoride vs control</td>
<td>&lt; .001</td>
<td>&lt; .001</td>
<td>&lt; .001</td>
<td>&lt; .001</td>
<td>.003</td>
</tr>
<tr>
<td></td>
<td>Nonfluoride vs control</td>
<td>.671</td>
<td>.669</td>
<td>.040</td>
<td>&lt; .001</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>0.022-inch</td>
<td>Fluoride vs nonfluoride</td>
<td>.152</td>
<td>.008</td>
<td>.356</td>
<td>&lt; .001</td>
<td>&lt; .001</td>
</tr>
<tr>
<td></td>
<td>Fluoride vs control</td>
<td>.042</td>
<td>&lt; .001</td>
<td>&lt; .001</td>
<td>&lt; .001</td>
<td>.001</td>
</tr>
<tr>
<td></td>
<td>Nonfluoride vs control</td>
<td>.465</td>
<td>.395</td>
<td>.006</td>
<td>&lt; .001</td>
<td>&lt; .001</td>
</tr>
</tbody>
</table>

Table 3  P values comparing the mean recovery loads at the largest and smallest
deflections for the different wires (as received [control], with [fluoride], and
without fluoride exposure [nonfluoride]) and both wire dimensions

<table>
<thead>
<tr>
<th>Wire diameter/group</th>
<th>Deflections (mm)</th>
<th>3.1 to 2.0</th>
<th>1.0 and 0.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.016-inch</td>
<td>Fluoride</td>
<td>&lt; .001</td>
<td>.897</td>
</tr>
<tr>
<td></td>
<td>Nonfluoride</td>
<td>&lt; .001</td>
<td>.500</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>&lt; .001</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>0.022-inch</td>
<td>Fluoride</td>
<td>&lt; .001</td>
<td>.045</td>
</tr>
<tr>
<td></td>
<td>Nonfluoride</td>
<td>&lt; .001</td>
<td>.370</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>&lt; .001</td>
<td>&lt; .001</td>
</tr>
</tbody>
</table>

Fig 1  Coefficient of variation at the various deflections for the
different wires (as received [control], with [fluoride] and without
fluoride exposure [nonfluoride]) and both wire dimensions.

Fig 2  Mean recovery load at the various deflections for the
different wires (as received [control], with [fluoride] and without
fluoride exposure [nonfluoride]) and the 0.016-inch dimension.

Fig 3  Mean recovery load at the various deflections for the
different wires (as received [control], with [fluoride] and without
fluoride exposure [nonfluoride]) and the 0.022-inch dimension.
DISCUSSION

The results of this study demonstrate that clinically used Ni-Ti wires have a reduced unloading curve when compared to as-received wires. The effect of the fluoride exposure was nonlinear. At great deflection, these wires had a lower unloading curve than the nonfluoride exposed wires, around 2.0 mm there was a crossover, and at the smallest deflections, they showed significantly higher unloading. Parenthetically, it should be noted that orthodontists would not typically use 0.016 × 0.022-inch Ni-Ti wires for tooth movements of 3.0 mm. One explanation for the difference between the intraoral wires at large deflections could be the study protocol, ie, the insertion of the wires first with fluoride exposure and then without. It is possible that the wires used for the first 6 weeks were more stressed than the second because the teeth were initially less well-aligned.

The results of this study are somewhat contradictory to that of Walker et al9 who demonstrated in a laboratory-only experiment that fluorides (topical gels Phos-flur and Prevident) decreased the mechanical properties of Ni-Ti wires. Perhaps the main reason for the dissimilar outcome could be the difference in study design. Both studies also differed in the type and dose of the applied fluoride. Although the dose difference of the two studies cannot be properly defined, it was likely higher in that of Walker et al.9 Finally, Walker et al9 exposed their wires to fluoride for 3 months, while in the present study, the fluoride regimen lasted only 6 weeks.

This study could have been designed as a randomized clinical trial. That is, instead of using the same 17 subjects, different individuals could have been enrolled to randomly assign all 34 subjects to one of the two treatment regimens. However, using the same patients for both parts of the study helped to neutralize some of the extrinsic confounding factors (including the difference in the original malocclusion, treatment plan, background fluoride, etc). In addition, maxillary and mandibular archwires could have been evaluated and analyzed separately rather than collectively.

Also, it could be debated as to why this study was initiated with the fluoride regimen. There exists a remote possibility that this could have led to remnants of small amounts of fluoride. The counterargument is that the earlier fluoride is applied in treatment, the more the patient will benefit from it. It is possible that a day or two “wash” between the fluoride and nonfluoride regimens would have been a logical consideration to make certain that the fluoride was out of the subjects’ systems. Another possibility could have been to randomly alternate the order of the fluoride and nonfluoride regimen. Finally, the current study did not investigate the topographical changes electron microscopically (or by x-ray diffractometry/photoelectron spectroscopy) as did Walker et al; this certainly would have aided in the interpretation of the results.

Wire performance has an impact on orthodontic tooth movement. To know what effect commonly prescribed fluoride regimens would have on the efficacy of orthodontic archwires should be in any orthodontist’s interest. Based on the findings of this investigation, fluoride-exposed 0.016 × 0.022-in Ni-Ti wires have sufficient unloading force to produce adequate tooth movements only after initial leveling and aligning when only tooth movements in the range of 0.5 and 1.0 mm are still required.

CONCLUSIONS

The results of this study are:

• Force degradation occurs when wires are exposed to the oral environment.
• Wires exposed to fluoride exhibit less force degradation than wires without fluoride exposure at 0.5 mm and 1.0 mm deflection, but they demonstrate a slightly higher force degradation at 3.0 and 3.1 mm deflection.
REFERENCES


