Fluoride influences nickel-titanium orthodontic wires' surface texture and friction resistance

Mona Aly Abbassy[1,2]

ABSTRACT

Objectives: The aim of this study was to investigate the effects exerted by the acidulated fluoride gel on stainless steel and nickel-titanium (Ni-Ti) orthodontic wires.
Materials and Methods: Sixty stainless steel and Ni-Ti orthodontic archwires were distributed into forty archwires used for *in vitro* study and twenty for *in situ* study. Fluoride was applied for 1 h in the *in vitro* experiment while it was applied for 5 min in the *in situ* experiment. The friction resistance of all wires with ceramic brackets before/after topical fluoride application was measured using a universal testing machine at 1 min intervals of moving wire. Moreover, surface properties of the tested wires before/after fluoride application and before/after friction test were examined by a scanning electron microscope (SEM). Dunnett's *t*-test was used to compare frictional resistance of as-received stainless steel wires and Ni-Ti wires to the wires treated by fluoride *in vitro* and *in situ* ($P < 0.05$). Two-way ANOVA was used to compare the effect of fluoride application and type of wire on friction resistance *in vitro* and *in situ* ($P < 0.05$).
Results: Ni-Ti wires recorded significantly high friction resistance after fluoride application when compared to stainless steel wires *in vitro*, $P < 0.05$. Fluoride application did not significantly affect the friction resistance of the tested wires *in situ*, $P < 0.05$. SEM observation revealed deterioration of the surface texture of the Ni-Ti wires after fluoride application *in vitro* and *in situ*.
Conclusions: The *in vitro* fluoride application caused an increase in friction resistance of Ni-Ti wires when compared to stainless steel wires. *In vitro* and *in situ* fluoride application caused deterioration in surface properties of Ni-Ti wires.

Key words: Fluoride, friction resistance, orthodontics, prophylaxis, surfaces

INTRODUCTION

Ceramic brackets were introduced in orthodontics to meet increasing esthetic demand among orthodontic patients nowadays;[1] however, many factors should be taken into consideration to avoid the high frictional forces generated between the ceramic bracket and the orthodontic archwire, which may interfere with orthodontic treatment outcome.[2-5]

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Friction is defined as a force that delays or resists the relative motion of two objects in contact, and its direction is tangential to the common interface of the two surfaces.[5,6] There are two types of friction: Kinetic (dynamic) which occurs during the motion and static which prevents the motion.[7]

Under normal conditions, the frictional force is proportional to the applied load depending on the nature of the sliding surfaces[7] and independent of the contact area between the surfaces and the sliding speed (except at very low speeds).[6]

Friction is an important factor in sliding mechanics where the archwire must slide through the bracket slots and tubes. This

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is obtained during the retraction of the teeth into an extraction area, active torque, leveling, and alignment.[1,6]

During sliding mechanics, the biologic tissues respond, and tooth movement occurs only when the forces applied exceed the friction on the bracket-wire interface. High levels of frictional force could result in the debonding of the bracket associated with either small dental movement or no movement at all.[6,8]

Thus, the correct selection of orthodontic brackets suitable for each case is the first step for achieving a proper orthodontic movement that can be applied to obtain optimum biologic tissue response.[4,6]

The proper selection of orthodontic wires is the second most important step for achieving the optimum orthodontic treatment, and thus, titanium alloy wires were introduced to the market with the advantage of providing light and continuous force and large amounts of activation for long periods.[4]

The third component to achieve successful orthodontic treatment is the maintenance of good oral hygiene and caries control. Fluoride prophylactic agents, such as acidulated phosphate fluorides (APFs), have been used extensively to prevent demineralization or remineralization of white spot lesions around orthodontic brackets. However, the fluoride ions in the prophylactic agents have been reported to cause corrosion and discoloration of titanium and its alloys.[9-11]

Optimum orthodontic movement can be achieved if the interaction between the three aforementioned components was studied well to allow an orthodontic treatment with minimal friction between the brackets and the wire.[12]

The aim of this study was to evaluate the friction resistance of nickel-titanium (Ni-Ti) and stainless steel wires to ceramic brackets before/after application of fluoride and to investigate the effect of topical fluoride application on the surface properties of Ni-Ti and stainless steel wires by scanning electron microscope (SEM).

MATERIALS AND METHODS

Sixty central incisor ceramic brackets standard edgewise (no built-in torque or tip) (Signature III, RMO, Inc., Denver, Colorado, USA) [Figure 1] with slots size 0.022 inch × 0.028 inch were used in this study. The summary for the groups is presented in Figure 2.

Two different wires with a cross-section of 019 inch ×0.025 inch currently used in orthodontics were investigated: One was stainless steel alloy Tru-Chrome Resilient archwire (RMO, Inc., Denver, Colorado, USA) and the second was preformed Ni-Ti orthonol superelastic archwire (RMO, Inc., Denver, Colorado, USA).

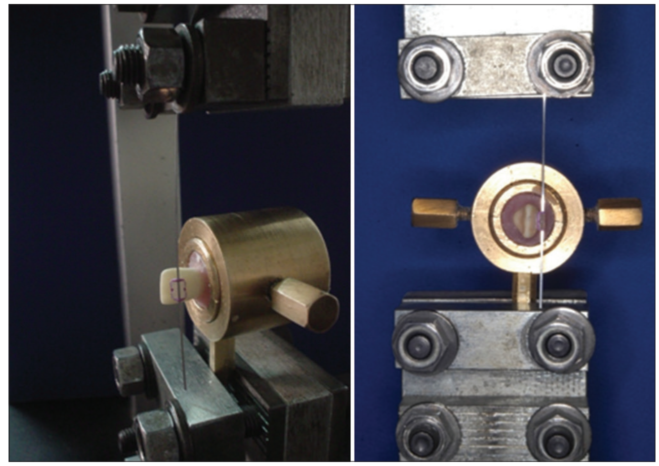

Figure 1: The archwire specimen is secured into the bracket slot

The topical fluoride agent used was APF (Nupro APF), 1.23% NaF, pH 3.9 (Dentsply International, York, PA, USA).

In vitro Study

The wires were divided into two groups having twenty specimens from each type of wire in each group. Half number of wire specimens in each group was immersed in fluoride gel for 1 h[12] while the remaining specimens in each group were not subjected to any fluoride treatment and acted as control.

In situ Study

Twenty orthodontic patients attending the clinic at the Department of Orthodontics (Faculty of Dentistry, Alexandria University) wearing full-bonded fixed orthodontic appliance were selected according to the following criteria:

All patients were young adults with permanent dentition ranging from 12 to 18 years old.

- All patients had their teeth leveled and aligned
- Each patient had a fixed orthodontic appliance with standard edgewise ceramic brackets (RMO, Inc., Denver, Colorado, USA)
- Brackets were bonded with no-mix chemical curing bonding resin (Reliance Orthodontics Products, Inc.)
- Good oral hygiene instructions were given to all patients.

Ten archwires with a cross-sectional dimension 0.019 inch × 0.025 inch from each group were placed in the patients' mouths, and the fluoride gel was applied into the applicator trays. The teeth were then air dried thoroughly, and trays were inserted with head tilted slightly forward. Patients were instructed to continue light biting action for 5 min with slight chewing motion to enhance interproximal coverage. Suction was used throughout treatment. Patients were instructed to expectorate after treatment, not to eat, drink, or rinse for 30 min.

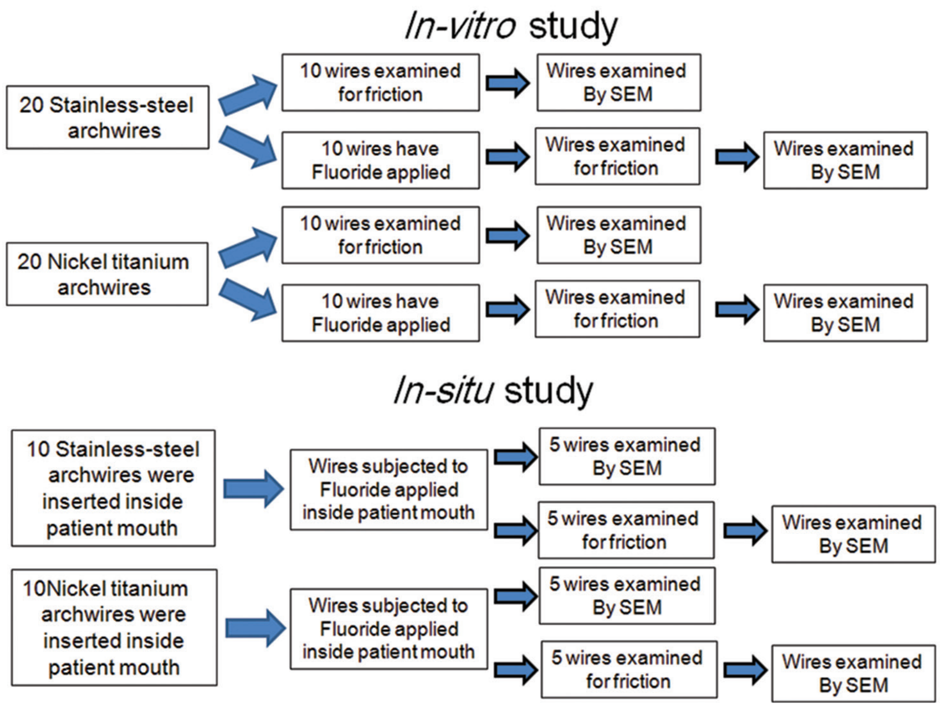

Figure 2: Summary for the experimental groups

Collection of the Archwires

The stainless steel and Ni-Ti archwires were left inside the patient mouth for 3 weeks. Then, they were collected with sterile instruments.

Frictional Force Examination

A total of sixty ivory central incisors were embedded with an acrylic resin block in a metallic mold where the self-cure acrylic resin was mixed and poured into the metal ring and then the teeth were embedded**.**

Sixty ceramic brackets were bonded on the labial surface of the ivory teeth using a bracket positioner.

The universal testing machine (Instron Corporation, Canten Industries, Inc., St. Petersburg, Florida, USA) was used for measuring the generated frictional force at the bracket-wire interface by sliding the wire through the bracket slot under small tangential displacements. The metallic mold was fixed firmly on the universal testing machine [Figure 1]. Then, posterior sections of each wire 4 cm long were inserted into the bracket slot.

All tested wire segments and brackets were cleaned with isopropyl alcohol before testing to remove any residue or debris. Elastomeric ligatures (American Orthodontics, Sheboygan, WI, USA) were placed over the bracket tie wings engaging the archwire. One end of the tested wire was left free, and the other end was attached firmly to the moving upper arm of the universal testing machine with 5 kg load cell. The tested wire was pulled upward through the bracket slot at a speed of 5 mm/min for 1 min.[4,13] Care was taken to avoid introducing torsion into the tested wire during clamping. The reading was set to give a zero reading after the wire was lightly tightened and was completely in a straight, vertical position toward the moving arm (upper fixture). This ensured that the only force transmitted by the moving arm to the wire and through the tested wires to the brackets was recorded as frictional force only.

The frictional force generated by each wire-bracket assembly was registered in kilograms by the tension load cell. After each test, the mold was removed and a new specimen was placed with a new ceramic bracket. New wire specimen was fitted into the bracket's slot. Then, the mold was fixed firmly on the testing machine, and the process was repeated for different archwire specimens. The load cell was calibrated before each measuring session. It recorded the static frictional force while the wire was drawn the same distance through different bracket-archwire assembly. Static frictional force was measured as the value of force needed to start the wire movement through the bracket slot. This force was measured as the maximal initial moving force on the universal testing machine digital display at 1 min intervals of moving wire.

Scanning Electron Microscope Examination

All specimens were examined before and after the friction test by an SEM (Jeol JSM–225-11-Scanning Microscope, Jeol Ltd., Tokyo, Japan) to determine the surface changes on the orthodontic wire after the friction test and the application of fluoride.

The wire specimens were mounted on copper stubs using silver glue, and then specimens were placed with standardized angle of tilt in the SEM, and photomicrographs were taken at a low magnification of ×150 and a higher magnification of ×500.

Statistical Analysis

The results were recorded and analyzed statistically using Dunnett's *t*-test to compare the frictional resistance means of the *in vitro* and *in vivo* experiments of the different wires used in this study to the control as-received specimens. Two-way ANOVA and Tukey test were used to compare the effect of the wire type and fluoride application on the frictional resistance of wires used in this study. All statistical examinations were carried out at a level of significance of $P < 0.05$.

RESULTS

Friction Resistance Test Results

Results revealed that the degree of friction generated at the bracket/archwire interface was affected by the type of archwire. The mean and standard deviation of frictional resistance of the two archwires are summarized in Figure 3.

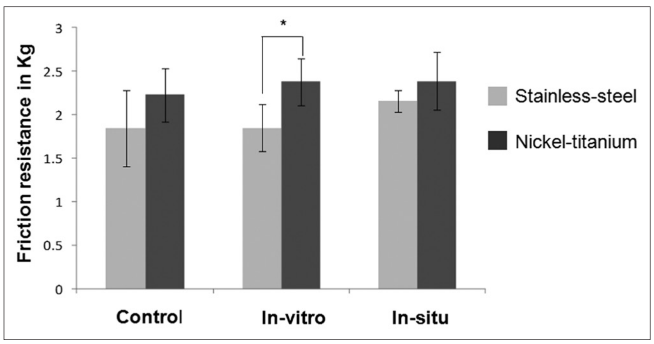

Figure 3: The frictional resistance values of the tested wires to ceramic brackets in kg. Values are presented as mean ± standard deviation. Significant differences between the groups are marked with asterisks ($P \leq 0.05$).

Paired *t*-test showed that there were no significant differences between the frictional resistance means of all wires' *in vitro* and *in situ* specimens when compared to their control specimens [Figure 3]. Two-way ANOVA and Tukey test showed that there was no significant difference between Ni-Ti wires when compared to stainless steel wires treated with fluoride *in situ;* however, the *in vitro* application of fluoride recorded high friction resistance between ceramic brackets and Ni-Ti wires when compared to stainless steel wires, $P < 0.05$.

Scanning Electron Microscope Evaluation

The observed surfaces of the as-received stainless steel wires showed that it exhibited a smooth surface before friction test [Figure 4a]. After friction test, fine tracks were observed [Figure 5a]. The as-received Ni-Ti side surface showed areas of longitudinal cracks and pits [Figure 4d]. After the friction test, areas of longitudinal cracks and pits were observed on the Ni-Ti wire surface along with deep line of draw for the wire through ceramic bracket resulting from the friction test [Figure 5d].

The *in vitro* application of fluoride exerted detrimental effects on the Ni-Ti wires with evident signs of surface corrosion either before or after friction test. Before the friction test, fluoride attacked the Ni-Ti surface causing masses of corrosive products and surface cracks [Figure 4e]. After the friction test [Figure 5e], major cracks were observed. However, the stainless steel wires showed less signs of surface deterioration either before or after the friction test [Figures 4b and 5b].

The application of fluoride in the *in situ* experiment confirmed that the results obtained from the *in vitro* experiment as less surface changes were observed on the surface of the stainless steel wires [Figures 4c and 5c] when compared to Ni-Ti wire specimens tested *in situ* [Figures 4f and 5f].

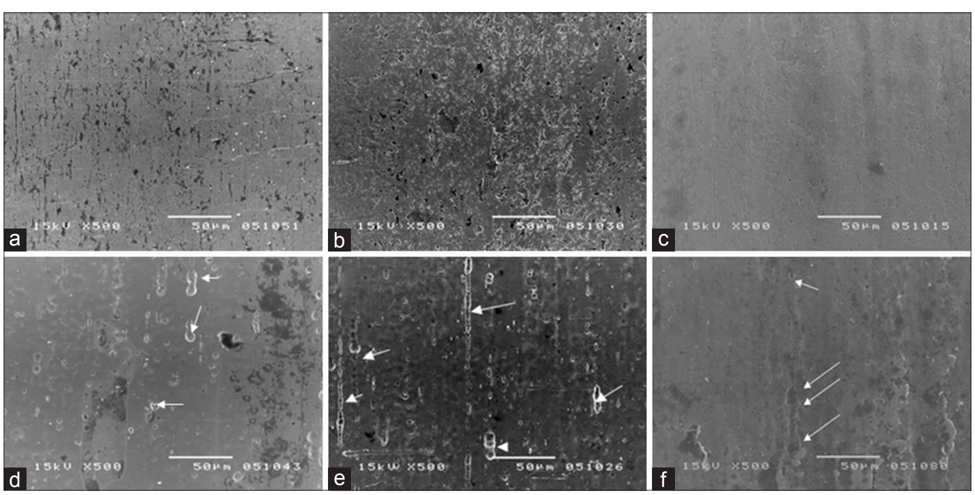

Figure 4: Scanning electron microscope pictures of tested wires before friction test. (a) As-received stainless steel wire showing smooth surface. (b) Stainless steel wire after *in vitro* fluoride application did not show significant defects. (c) Stainless steel wire after *in situ* fluoride application did not show significant defects. (d) As-received nickel-titanium wire. White arrows show areas of longitudinal cracks. (e) Nickel-titanium wires after *in vitro* fluoride application with major cracks marked with white arrows. (f) Nickel-titanium after *in situ* fluoride application. White arrows point to numerous areas of longitudinal defects

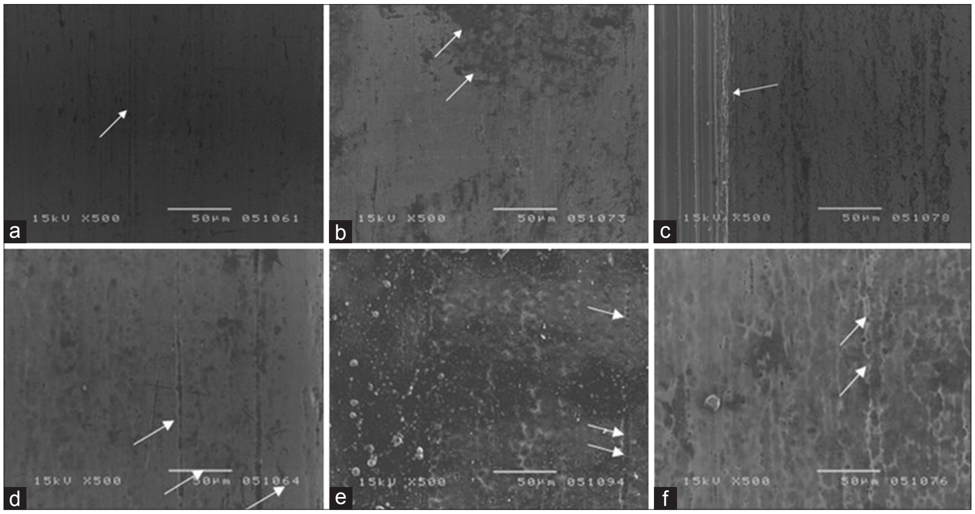

Figure 5: Scanning electron microscope pictures of tested wires after friction test. (a) As-received stainless steel wire showing smooth surface. Arrow points to line of wire draw. (b) Stainless steel wire after *in vitro* fluoride application. Arrows show line of wire draw. (c) Stainless steel after *in situ* fluoride application. Arrow shows line of wire draw. (d) As-received nickel-titanium wire. Arrow shows areas of longitudinal defects. (e) Nickel-titanium wires after *in vitro* fluoride application. Arrows show cracks. (f) Nickel-titanium after *in situ* fluoride application. Arrows point to longitudinal defects

DISCUSSION

Titanium and its alloys are widely used in orthodontic field due to their superelastic property, excellent ductility, good fatigue life, low elastic modulus, high springback, and high weldability as compared to the conventional stainless steel orthodontic wires.[4,14]

However, the Ni-Ti orthodontic wires' mechanical and surface characterization might be negatively influenced by the chemical components of various agents used for oral care. Thus, the current study aimed at exploring the effects of APF agent that was applied *in vitro* and *in situ*[15-17] on a Ni-Ti orthodontic wire and comparing them to the conventionally used stainless steel orthodontic wire. All the tested wires used in this study were rectangular wires because these types of wires offer control in all the three planes which facilitated their testing procedures.[16]

The selected duration of fluoride application in the *in situ* study was according to the manufacturer's instructions. However, the adopted duration in the *in vitro* study was 60 min which corresponds to 21 days of daily tooth brushing (equivalent to average follow-up period during orthodontic treatment).

In the *in situ* study, all patients had their teeth leveled and aligned with the wires placed with no force applied on them to avoid any significant mechanical distortion to the tested wires that may affect their corrosion behavior before their examination.[14]

Ceramic brackets were used in the current study because previous reports showed that they are sensitive to the change in surface texture of the orthodontic wires attached to them leading to the increase in friction resistance between orthodontic brackets and wires and consequently affecting the resulting orthodontic forces delivered to the orthodontically treated teeth.[8,18]

The obtained results of the current experiment showed that fluoride caused deterioration of the Ni-Ti wires' surface texture and a concomitant increase in its friction resistance to ceramic brackets which was clearly evident from the *in vitro* experiment obtained results, which may be attributed to the fact that the corrosion behavior of the titanium containing alloys depend on an oxide film composed of mainly titanium oxide on the surface,[19-21] which spontaneously covers the surface of titanium and its alloys in the presence of oxygen. This oxide film undergoes a reaction in fluoride solutions, resulting in the formation of titanium fluoride, titanium oxide fluoride, or sodium titanium fluoride on the surface of the alloys. Hence, the corrosion resistance of those alloys decreases markedly in these solutions.[22,23] The destruction of the oxide layer may lead to the absorption of hydrogen from various solutions because of the high affinity of titanium to hydrogen, which is known as hydrogen embrittlement.

On the other hand, the corrosion resistance of the stainless steel is ascribed mainly to the presence of Cr_2O_3 in the passive film formed on its surface; this film is thought to be more chemically stable than the titanium oxide layer formed on the titanium containing alloys.[24-27]

Application of fluoride in the *in situ* experiment did not cause significant effect on the friction resistance between ceramic and titanium wires. This can be explained by the buffering effect exerted by the saliva on the APF solution, in addition to its dilution effect. Moreover, when orthodontic wires are exposed to the oral environment, a noncellular acquired film is rapidly organized on the material surface by spontaneous adsorption of extracellular macromolecules composed of glycoproteins and proteoglycans. Hence, it is speculated that the aforementioned factors diminished the effect of fluoride on Ni-Ti wires *in situ*.[15,28,29]

There should be great care when interpreting the obtained results of the current experiment to the clinical situation because orthodontic wires are usually exposed to fatigue stresses during orthodontic tooth movement making them more liable to corrosion.[30] Moreover, continuous contact of the Ni-Ti wires to various consistencies and pH of different food substances may cause various chemical changes that may enhance corrosion of these wires.

Further research is needed to investigate the exact biological effect of the released ions from the corrosion process of the titanium-containing wires on the oral environment *in vivo*.

CONCLUSIONS

This study showed the liability of Ni-Ti wires to corrosion when exposed to high concentration of fluoride containing agents. The as-received Ni-Ti wires showed roughness of their surfaces and significantly increased friction to ceramic brackets when compared to stainless steel wires. Moreover, application of topical fluoride caused deterioration of surface properties of Ni-Ti wires. Therefore, it is highly recommended to take into consideration the content of the oral health care products utilized by the patients when recommending these agents to orthodontic patients treated by Ni-Ti wires.

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Nil.

Conflicts of Interest

There are no conflicts of interest.

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