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Effects of two Fluoride Mouthwashes on Surface Topography and Frictional Resistance of Orthodontic Wires

Eilnaz Ehrami[1], Alireza Omrani[1*], Masood Feizbakhsh[1]

1. Department of Orthodontics, School of Dentistry, Isfahan (Khorasgan) Branch, Islamic Azad University, Isfahan, Iran

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**** Corresponding author:***
Department of Orthodontics, School of Dentistry, Isfahan (Khorasgan) Branch, Islamic Azad University, Isfahan, Iran

Email: dr.elnaz59@gmail.com

ABSTRACT

Objectives: We compared the effects of fluoride mouthwashes on surface topography of orthodontic wires, and static and kinetic frictional forces between stainless-steel (SS) orthodontic brackets and SS and nickel-titanium (NiTi) archwires.

Materials and Methods: This in vitro, experimental study evaluated 240 standard SS maxillary central incisor brackets and 0.018-, and 0.025×0.019-inch NiTi and SS archwires. Different combinations of wire diameters and wire types were exposed to artificial saliva (control), 0.05% sodium-fluoride (NaF) for 1 minute daily, or 0.2% NaF for 1 minute weekly (37°C) for 3 months. The wires were pulled in the bracket slots by 5mm in a universal testing machine (10mm/minute). The static and kinetic forces were measured. The surface topography of the wires was inspected under a scanning electron microscope (SEM). Three-way ANOVA followed by Bonferroni post-hoc tests were used for statistical analysis ($P<0.05$).

Results: The mean static and kinetic frictional forces of 0.025×0.019- inch NiTi wired in the 0.05%NaF group were significantly greater than the SS wire. The mean kinetic frictional force in the 0.05%NaF group was significantly greater than the 0.2%NaF and artificial saliva groups for all wires. The mean static and kinetic forces in 0.2%NaF were significantly greater than in artificial saliva. In all groups, larger wires showed higher mean frictional forces. SEM results revealed higher wire surface roughness in the 0.05%NaF group followed by the 0.2%NaF group.

Conclusion: Weekly use of 0.2%NaF mouthwash is recommended during sliding mechanics to minimize frictional forces between SS and NiTi wires and SS brackets.

Keywords: Orthodontic Brackets; Sodium Fluoride; Friction; Mouthwashes

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INTRODUCTION

Comprehensive orthodontic treatment usually includes three phases of leveling and alignment, space closure and anterior/posterior correction, and detailing and finishing [1]. Orthodontic tooth movement for space closure can be performed by two mechanical techniques. The first technique is frictionless, and involves the use of closing loops. The second technique is the sliding technique, which refers to the sliding movement of wires in the bracket slots and tubes, and is also known as the frictional technique. Presence/absence of friction is the main difference between these two techniques [2,3]. At present, the sliding technique has gained increasing popularity among orthodontists due to its simplicity. The frictional resistance between the bracket slot and wire affects orthodontic tooth movement, and controlling this friction during the sliding mechanics is an important factor in achieving optimal treatment results. Several factors can directly or indirectly affect the amount of friction between the wires and brackets [4]. Frictional resistance has an inhibitory effect on the treatment process, and can decrease or event impede orthodontic tooth movement and result in anchorage loss.

Considering the increasing demand of patients for orthodontic treatment, special attention should be paid to oral hygiene as an important factor in success of orthodontic treatment. Any neglect in this respect can lead to demineralization and dental caries, compromising the esthetic outcome of treatment. Fluoride mouthwashes containing 0.05% and 0.2% fluoride for daily and weekly use, respectively can greatly improve the oral hygiene of patients during the course of treatment [5,6]. Use of mouthwashes and other prophylactic agents containing fluoride can cause some changes in the oral environment. Although titanium and stainless steel (SS) wires have a passive corrosion-resistant oxide coating, products containing fluoride with a pH of 3.5 to 7 can damage this oxide layer and cause corrosion and discoloration, and alter the mechanical properties of orthodontic wires [7]. Also, the hydrofluoric acid formed following the use of sodium-fluoride (NaF) mouthwash can react with the passive oxide coating of SS alloys and degrade it [6]. The majority of orthodontic patients are young adults that do not have a satisfactory oral hygiene, and are at high risk of caries and demineralization. Thus, it is important to find an oral hygiene adjunct to minimize the risk of enamel demineralization and caries with no adverse effect on mechanical properties of orthodontic wires. Although fluoride can affect the friction between the wires and brackets, its effect has been less commonly addressed. Thus, this study aimed to compare the effects of two fluoride mouthwashes on surface topography of orthodontic wires, and static and kinetic frictional forces between the SS orthodontic brackets and SS and nickel-titanium (NiTi) archwires.

MATERIALS AND METHODS

This in vitro, experimental study evaluated 240 standard SS maxillary central incisor brackets with 0.022-inch slot size (Ortho-Organizer; Carlsbad, CA, USA), 0.018, and 0.019x0.025 inch NiTi and SS wires (Ortho-Organizer; Carlsbad, CA, USA) and O-rings (Ortho-Organizer; Carlsbad, CA, USA).

The sample size was calculated to be 15 in each group assuming α=0.05, effect size=0.25, and study power of 90% using three-way ANOVA feature of G Power software. To increase the accuracy, 20 samples were included for each group [8]. The study included three groups of control [artificial saliva with the formulation of 0.844mg sodium chloride, 1.2mg potassium chloride, 0.146mg calcium chloride anhydrous, 0.052mg magnesium chloride 6 H2O, 0.34mg potassium phosphate dibasic, 60 mg sorbitol solution (70%), 2mg methyl paraben, and 3.5mg hydroxyethyl cellulose], 0.05% NaF mouthwash (Orthokin; Cosmodent, Spain), and 0.2% NaF mouthwash (Orthokin; Cosmodent, Spain). SS and NiTi wires (0.018, and 0.019×0.025 inch) were used in all three groups. Thus, each group had four subgroups, and each subgroup included 20 brackets (a total of 240 brackets) (Table 1). All tests were performed in dry environment at 23°C.

Group 1 (0.05% NaF): In this group, the bracket and wire sets were immersed in 0.05% NaF (Orthokin; Cosmodent, Spain) for 1min daily. Next, they were transferred into artificial saliva and incubated at 37°C until the next day.

Table 1. Study-group breakdown based on type and thickens of the orthodontic wires

Group	Wire type	Wire diameter (inch)
0.05% sodium-fluoride mouthwash	Stainless steel	0.018
		0.019×0.025
	Nickel-titanium	0.018
		0.019×0.025
0.2% sodium-fluoride mouthwash	Stainless steel	0.018
		0.019×0.025
	Nickel-titanium	0.018
		0.019×0.025
Artificial saliva	Stainless steel	0.018
		0.019×0.025
	Nickel-titanium	0.018
		0.019×0.025

Fig. 1. Custom-made device for placement of bracket and wire sets in the universal testing machine

This mouthwash has 0.05wt% NaF and a pH of 5.1-5.2. The pH of the solution was measured by a pH meter (COM300; HM Digital, Seoul, Korea) with 1% accuracy.

Group 2 (0.2% NaF): In this group, the bracket and wire sets were immersed in 0.2% NaF (Orthokin; Cosmodent, Spain) for 1 min once a week. Next, they were transferred into artificial saliva and incubated at 37°C until the next week. This mouthwash has 0.2wt% NaF, and a pH of 5.2.

Group 3 (control): In this group, the bracket and wire sets were immersed in artificial saliva with a pH of 6.75 with the following formulation: 0.844mg sodium chloride, 1.2 mg potassium chloride, 0.146mg calcium chloride anhydrous, 0.052mg magnesium chloride 6 H2O, 0.34mg potassium phosphate dibasic, 60 mg sorbitol solution (70%), 2 mg methyl paraben, and 3.5mg hydroxyethyl cellulose [6-8]. The solution was refreshed daily.

Fresh solutions were used each time. This process was repeated for 3 months for all three groups. At the end of each month, the O-rings were replaced to better simulate the clinical setting.

To assess the change in surface topography of the wires, 5 wires from each group were inspected under a scanning electron microscope (SEM; XL30; Philips, Netherlands) at x500 magnification before and after the interventions. The specimens were mounted on stubs using carbon fiber duct tape. To improve image quality, the specimens were gold sputter coated for 300 seconds with <4 nm thickness in a sputter coater. For better electrical conductance, the studs were connected to the microscope stage with copper conductive tape. The before and after SEM images were compared, and the changes in surface topography were recorded.

The 30-mm end part of the NiTi archwires and the 30-mm end part of SS archwires were cut, and the remaining two ends of the wires formed a loop for attachment to a universal testing machine (H2SKS; Hounsfield, UK), equipped with 150g load (to simulate the amount of force applied for movement of canine tooth by the sliding technique in the clinical setting) [1]. To better simulate the clinical setting, the brackets were attached to the wires with O-rings and immersed in the solutions. The bracket and wire sets were then placed in a custom-made device (Figure 1). The device was made from aluminum and measured 30x27cm. This device was firmly fixed to the universal testing machine with screw. The designed device had a hook in which, the bracket would be fixed such that the wire in the bracket slot could be pulled with no change in direction or angulation. By doing so, we minimized the possible operator errors related to designing the jig and fixing of the bracket in the machine. The universal testing machine caused the sliding of wire in the bracket slot by applying 150g force to quantify the amount of force required to overcome the frictional resistance between the bracket and wire [1]. One end of the wire was attached to 150g load and the other end was tied to the universal testing machine. The wire was pulled at a speed of 10mm/min [9] in the bracket slot by 5mm. The computer connected to the universal testing machine drew the force graph. The maximum point of the graph indicated the static friction (resistance against primary movement and initiation of movement) while the mean point (resistance along the path of movement) indicated the dynamic or kinetic friction. The force was recorded in Newtons (N). Data were analyzed using SPSS version 24 (SPSS Inc., IL, USA). Three-way ANOVA was applied to assess the main and interaction effects of the wire type, wire diameter, and type of mouthwash on dynamic and static frictional forces. The Bonferroni post-hoc test was applied for pairwise comparisons. Level of significance was set at 0.05.

RESULTS

Table 2 presents the mean kinetic frictional forces based on the type of wire, diameter and mouthwash. Three-way ANOVA was conducted on the effect of three independent variables of wire type (NiTi and SS), wire diameter (0.018, 0.019-0.025) and mouthwash type (0.2% NaF, 0.05% NaF, and artificial saliva) and their interaction effects on the kinetic frictional forces. The effects of wire type [F (1.228)=3.975, P=0.047, η^2=0.017), wire diameter [F (1.228)=154.38, P<0.001, η^2=0.404) and mouthwash type [F (2,228)=50.89, P<0.001, η^2=0.182). were found to be significant. The interaction effects of wire type and wire diameter [F (1.228)=31.28, P<0.001, η^2=0.215), and wire type and mouthwash type [F (2.228)=18.140, P<0.001, η^2=0.137) were also significant. But the interaction effect of wire diameter and mouthwash type [F (1.228)=2.00, P=0.138, η^2=0.017) was not significant.

The three-way interaction effect was also significant [F (2.228)=15.71, P<0.001, η^2=0.121). The Bonferroni post-hoc test was then applied, which revealed that in 0.018-inch wire diameter and 0.2% NaF group, the mean dynamic frictional force was significantly higher in SS wires compared with NiTi wires (P<0.001). However, the difference in this regard was not significant between SS and NiTi wires in 0.05% NaF (P=0.119) or artificial saliva (P=0.300). In 0.019-0.025-inch diameter and 0.05% NaF mouthwash group, the mean dynamic frictional force in SS wire was significantly lower than that in NiTi wire (P<0.001). However, the difference in this regard was not significant between SS and NiTi wires in 0.2% NaF (P=0.126) or artificial saliva (P=0.620).

In NiTi wires immersed in 0.2% NaF, 0.05% NaF and artificial saliva, the mean dynamic frictional force of 0.019-0.025-inch wires was significantly higher than that of 0.018-inch wires (P<0.001).

In SS wires immersed in 0.2% NaF (P=0.066) and 0.05% NaF (P=0.189), no difference was found in dynamic frictional force between 0.019-0.025-inch and 0.018-inch wires.

Table 2. Mean kinetic frictional forces based on wire type, wire diameter and immersion liquid

Wire diameter	Groups	Nickel-titanium wire			Stainless steel wire			Total		
		N	Mean	SD	N	Mean	SD	N	Mean	SD
0.018-inch	0.2% sodium-fluoride	20	0.18	0.02	20	0.3	0.05	40	0.24	0.07
	0.05% sodium-fluoride	20	0.34	0.09	20	0.39	0.07	40	0.36	0.08
	Artificial saliva	20	0.25	0.07	20	0.29	0.05	40	0.27	0.06
	Total	60	0.26	0.09	60	0.327	0.07	120	0.29	0.09
0.019-0.025-inch	0.2% sodium-fluoride	20	0.4	0.08	20	0.36	0.13	40	0.38	0.11
	0.05% sodium-fluoride	20	0.67	0.22	20	0.35	0.03	40	0.51	0.23
	Artificial saliva	20	0.46	0.11	20	0.48	0.08	40	0.47	0.1
	Total	60	0.51	0.19	60	0.39	0.11	120	0.45	0.16
Total	0.2% sodium-fluoride	40	0.29	0.13	40	0.33	0.1	80	0.31	0.11
	0.05% sodium-fluoride	40	0.5	0.24	40	0.37	0.06	80	0.44	0.18
	Artificial saliva	40	0.36	0.14	40	0.38	0.12	80	0.37	0.13
	Total	120	0.38	0.19	120	0.36	0.1	240	0.37	0.15

Table 3. Mean static frictional forces based on wire type, wire diameter and immersion liquid

Wire diameter	Groups	Nickel-titanium wire			Stainless steel wire			Total		
		N	Mean	SD	N	Mean	SD	N	Mean	SD
0.018-inch	0.2% sodium-fluoride	20	0.41	0.15	20	0.4	0.08	40	0.41	0.12
	0.05% sodium-fluoride	20	0.47	0.2	20	0.62	0.14	40	0.55	0.19
	Artificial saliva	20	0.42	0.16	20	0.5	0.15	40	0.46	0.16
	Total	60	0.43	0.17	60	0.51	0.15	120	0.47	0.17
0.019-0.025-inch	0.2% sodium-fluoride	20	1.09	0.43	20	1.09	0.38	40	1.09	0.4
	0.05% sodium-fluoride	20	1.19	0.38	20	0.72	0.19	40	0.95	0.38
	Artificial saliva	20	1.07	0.21	20	1.11	0.22	40	1.09	0.21
	Total	60	1.12	0.35	60	0.98	0.33	120	1.05	0.34
Total	0.2% sodium-fluoride	40	0.75	0.47	40	0.75	0.44	80	0.75	0.45
	0.05% sodium-fluoride	40	0.83	0.47	40	0.67	0.17	80	0.75	0.36
	Artificial saliva	40	0.74	0.37	40	0.81	0.36	80	0.77	0.37
	Total	120	0.77	0.44	120	0.74	0.34	240	0.76	0.39

Table 4. Pairwise comparisons of dynamic and static frictional forces of nickel-titanium and stainless steel wires based on the wire diameter and immersion liquid by the Bonferroni post-hoc test

Wire diameter	Groups	(I)	(J)	Kinetic		Static	
				Mean Difference (I-J)	P	Mean Difference (I-J)	P
0.018-inch	0.2% sodium-fluoride	NiTi	SS	-0.119*	<0.001	0.006	0.935
	0.05% sodium-fluoride	NiTi	SS	-0.051	0.119	-0.153	0.056
	Artificial saliva	NiTi	SS	-0.033	0.300	-0.086	0.282
0.019-0.025-inch	0.2% sodium-fluoride	NiTi	SS	0.050	0.126	0.001	0.990
	0.05% sodium-fluoride	NiTi	SS	0.327*	<0.001	0.470*	<0.001
	Artificial saliva	NiTi	SS	-0.016	0.620	-0.049	0.539

NiTi: nickel-titanium; SS: Stainless steel
* Significant

However, in artificial saliva, the mean dynamic frictional force in 0.019-0.025-inch wires was significantly higher than that in 0.018-inch wire (P<0.001). In NiTi wire with 0.018-inch diameter, the mean dynamic frictional force was significantly higher in 0.05% NaF compared with 0.2% NaF (P<0.001) and artificial saliva (P=0.027). However, the difference in this respect was not significant between 0.2% NaF and artificial saliva (P=0.060). In NiTi wire with 0.019-0.025-inch diameter, the mean dynamic frictional force in 0.05% NaF was significantly higher than that of 0.2% NaF (P<0.001) and artificial saliva (P<0.001). However, the difference between 0.02% NaF and artificial saliva was not significant (P=0.235).
In SS wire with 0.018-inch diameter, the mean dynamic frictional force in 0.05% NaF was significantly higher than that in 0.2% NaF (P=0.014) and artificial saliva (P=0.005). However, the difference between 0.2% NaF and artificial saliva was not significant (P=1.00). In SS wire with 0.019-0.025-inch diameter, the mean dynamic frictional force in artificial saliva was significantly higher than that in 0.05% NaF (P<0.001) and 0.2% NaF (P=0.001), but the difference between 0.05% NaF and 0.2% NaF was not significant (P=1.00). Table 3 presents the mean static frictional forces based on wire type, wire diameter and mouthwash type. Three-way ANOVA was conducted on the effect of three independent variables of wire type (NiTi and SS), wire diameter (0.018, 0.019-0.025) and mouthwash type (0.2% NaF, 0.05% NaF, and artificial saliva) and their interaction effects on the static frictional forces.

Table 5. Pairwise comparisons of dynamic and static frictional forces of 0.018 and 0.019-0.025-inch wire diameters based on the wire type and immersion liquid by the Bonferroni post-hoc test

Wire type	Groups	(I)#	(J)#	Kinetic		Static	
				Mean Difference (I-J)	P	Mean Difference (I-J)	P
NiTi	0.2% NaF	0.018	0.019-0.025	-0.22*	<0.001	-0.68*	<0.001
	0.05% NaF	0.018	0.019-0.025	-0.33*	<0.001	-0.71*	<0.001
	Artificial saliva	0.018	0.019-0.025	-0.20*	<0.001	-0.64*	<0.001
SS	0.2% NaF	0.018	0.019-0.025	-0.05	0.066	-0.69*	<0.001
	0.05% NaF	0.018	0.019-0.025	0.04	0.189	-0.09	0.232
	Artificial saliva	0.018	0.019-0.025	-0.19*	<0.001	-0.61*	<0.001

NiTi: nickel-titanium; SS: Stainless steel; NaF: sodium-fluoride
Diameter (inch); * Significant

Table 6. Pairwise comparisons of dynamic and static frictional forces of immersion liquid based on the wire type and wire diameter by the Bonferroni post-hoc test

Wire type	Diameter (inch)	(I)	(J)	Kinetic		Static	
				Mean Difference (I-J)	P	Mean Difference (I-J)	P
NiTi	0.018	0.2% NaF	0.05% NaF	-0.16*	<0.001	-0.06	1
		Artificial saliva	0.2% NaF	0.07	0.06	0.01	1
			0.05% NaF	-0.08*	0.027	-0.05	1
	0.019-0.025	0.2% NaF	0.05% NaF	-0.26*	<0.001	-0.09	0.719
		Artificial saliva	0.2% NaF	0.05	0.235	-0.03	1
			0.05% NaF	-0.21*	<0.001	-0.12	0.36
SS	0.018	0.2% NaF	0.05% NaF	-0.09*	0.014	-0.22*	0.01
		Artificial saliva	0.2% NaF	-0.01	1	0.09	0.64
			0.05% NaF	-0.1*	0.005	-0.12	0.39
	0.019-0.025	0.2% NaF	0.05% NaF	0.01	1	0.375*	<0.0
		Artificial saliva	0.2% NaF	0.12*	0.001	0.021	1
			0.05% NaF	0.13*	<0.001	0.396*	<0.0

NiTi: nickel-titanium; SS: Stainless steel; NaF: sodium-fluoride
* Significant

The effect of wire diameter [F (1.228)=312.38, P<0.001, η^2=0.578] was significant but the effects of wire type [F (1.228)=0.942, P=0.333, η^2=0.004) and mouthwash type [F (2.228)=0.248, P=0.781, η^2=0.002) were not significant. The interaction effects of wire type and wire diameter [F (1.228)=11.233, P=0.001, η^2=0.047], wire type and mouthwash type [F (2.228)=4.201, P=0.016, η^2=0.036), and wire diameter and mouthwash type [F (1,228)=6.943, P=0.001, η^2=0.057) were all significant. The three-way interaction [F (2.228)=9.705, P<0.001, η^2=0.078) was also significant. The Bonferroni post-hoc test was then applied, which revealed that the mean static frictional force was not significantly different in SS and NiTi wires with 0.018-inch diameter immersed in 0.2% NaF (P=0.935), 0.05% NaF (P=0.056) and artificial saliva (P=0.282). The mean static frictional force of SS wires was significantly lower than that of NiTi wires with 0.019-0.025-inch diameter immersed in 0.05% NaF (P<0.001). However, the difference between SS and NiTi wires was not significant in 0.2% NaF (P=0.990) or artificial saliva (P=0.620).

In NiTi wires immersed in 0.2% NaF, 0.05% NaF, and artificial saliva, the mean static frictional force of 0.019-0.025-inch wires was significantly higher than that of wires with 0.018-inch diameter (P<0.001).

In SS wires immersed in 0.05% NaF, no significant difference was noted in static frictional force between 0.019-0.025 and 0.018-inch diameters (P=0.232).

However, in 0.2% NaF and artificial saliva, the mean static frictional force of wires with 0.019-0.025-inch diameter was significantly higher than that of wires with 0.018-inch diameter (P<0.001).

In 0.018-inch NiTi wire, the mean static frictional force was not significantly different between 0.05% NaF and 0.2% NaF (P=1.00), 0.05% NaF and artificial saliva (P=1.00), and 0.2% NaF and artificial saliva (P=1.00).

In 0.019-0.025-inch NiTi wire, the mean static frictional force was not significantly different between 0.05% NaF and 0.2% NaF (P=0.719), 0.05% NaF and artificial saliva (P=0.368), and 0.2% NaF and artificial saliva (P=1.00).

In 0.018-inch SS wire, the mean static frictional force in 0.05% NaF was significantly higher than that in 0.2% NaF (P=0.018). However, the differences between 0.05% NaF and artificial saliva (P=0.391) and 0.2% NaF and artificial saliva (P=0.640) were not significant. In 0.019-0.025-inch SS wire, the mean static frictional force in 0.05% NaF was significantly lower than that in 0.2% NaF and artificial saliva (P<0.001) but the difference between 0.2% NaF and artificial saliva was not significant (P=1.00). Tables 4-6 show the results of pairwise comparisons by the Bonferroni test.

Fig. 2. Surface topography of 0.018-inch stainless steel wires in different subgroups; (a) before immersion, (b) control, (c) 0.2% sodium-fluoride, (d) 0.05% sodium-fluoride

SEM results:

SEM assessment revealed roughening and increased porosities on the surface of SS and NiTi wires in all three groups. Qualitative increase in surface roughness and porosities was maximum in the 0.05% NaF group followed by the 0.2% NaF group and the controls. The mouthwashes had maximum effect on surface topography of NiTi wires. Also, maximum change in surface topography was noted in 0.019x0.025-inch NiTi wires immersed in 0.05% NaF mouthwash daily. Figures 2-5 show the surface topography of different wires in different subgroups.

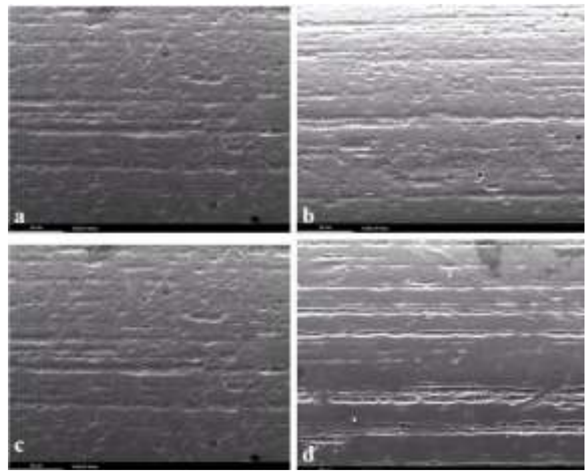

Fig. 3. Surface topography of 0.018-inch nickel-titanium wires in different subgroups; (a) before immersion, (b) control, (c) 0.2% sodium-fluoride; (d) 0.05% sodium-fluoride

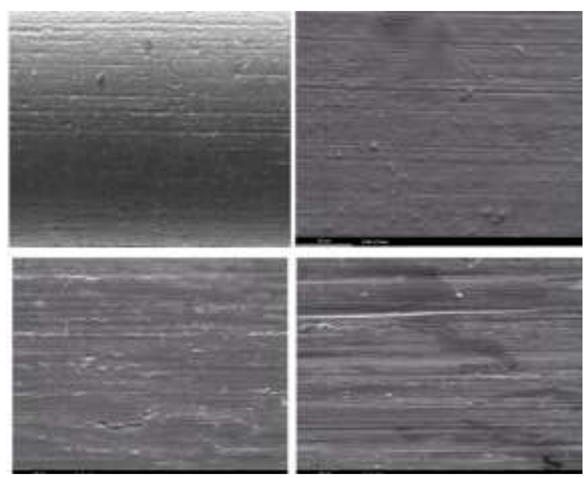

Fig. 4. Surface topography of 0.019×0.025-inch stainless steel wires in different subgroups; (a) before immersion, (b) control, (c) 0.2% sodium-fluoride; (d) 0.05% sodium-fluoride

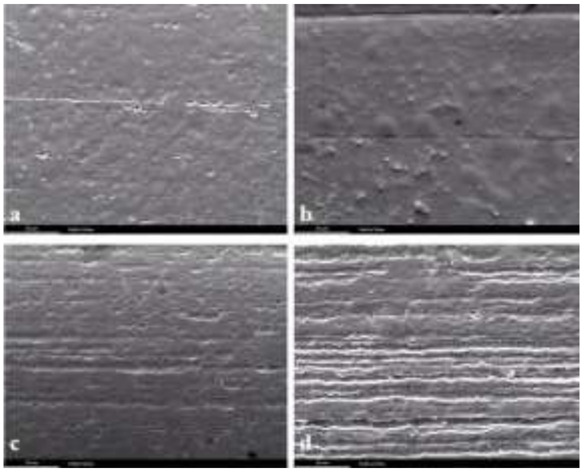

Fig. 5. Surface topography of 0.019×0.025-inch nickel-titanium wires in different subgroups; (a) before immersion, (b) control, (c) 0.2% sodium-fluoride, (d) 0.05% sodium-fluoride

DISCUSSION

This study compared the effects of two fluoride mouthwashes on surface topography of orthodontic wires, and static and kinetic frictional forces between the SS orthodontic brackets and SS and NiTi archwires. The results showed that wire diameter, type of mouthwash, and type of wire all affected the static and kinetic frictional forces ($P<0.05$). The minimum kinetic and static forces were noted in artificial saliva group followed by 0.2% NaF group. The forces were maximum in 0.05% NaF group. Fluoride-containing products have a pH range of 3.5 to 7. They release fluoride ions, which damage the oxide layer formed on titanium surfaces. In acidic environments, small amounts of fluoride form hydrofluoric acid, which can dissolve the oxide layer and cause its roughness and corrosion. This can occur to both NiTi and SS alloys. However, due to different chemical composition, the reactions may vary [6]. In the present study, 0.05% NaF group showed higher mean kinetic and static forces than 0.2% NaF group, which was different from the results of Walker et al, [6] and Kao et al [7]. Our results showed that the frequency of mouthwash use (daily or weekly) had a greater effect than the concentration of mouthwashes on frictional forces. In other words, different results may be obtained by taking into account the washing effect of the saliva and the frequency of mouthwash use. These parameters may explain the variability in the results of studies on this topic. In the present study, the washing effect of the saliva was taken into account since the wires were exposed to mouthwashes only for 1 min each time, and were stored in artificial saliva for the rest of the day/week, which is close to the clinical setting.

It has been shown that hydrogen uptake and destruction of passive coating of orthodontic wires have a direct correlation with longer immersion time and fluoride concentration [10]. Unlike previous studies, we exposed the wires to mouthwashes for 1 min each time to better simulate the clinical setting, which was a strength of this study. Also, unlike previous studies that assessed the effect of different concentrations of the same mouthwash for the same period of time on frictional forces, we assessed the effect of two concentrations of the same mouthwash and the frequency of use (daily versus weekly) on frictional forces, which was another strength of this study. Our results indicated that the effect of weekly use of NaF mouthwash with higher fluoride concentration on frictional forces was lower than the effect of daily use of lower concentration of the same mouthwash. This finding highlights the role of saliva in reduction of friction, which has not been taken into account in previous studies. It appears that the washing effect of the saliva on reduction of friction is more important than the effect of mouthwashes on increase of friction.

The present study showed that the mean static force was not significantly different based on the type of wire (irrespective of wire diameter and type of mouthwash). This result was in agreement with that of Kapur et al [11]. They reported that beta-titanium wires had higher static and kinetic frictional forces than SS and NiTi wires but they found no significant difference in static frictional force between the SS and NiTi wires. In our study, type of wire significantly affected the kinetic force irrespective of other variables. Also, the mean static and kinetic forces were greater in 0.019×0.025-inch SS and NiTi wires compared with 0.018-inch SS and NiTi wires. The reason can be the larger contact area between the bracket and wire when larger wires are used, which can increase the friction. This result was in agreement with that of Mirzaie et al [12]. In our study, the mean static force was not significantly different in the three immersion groups (irrespective of other variables) while the mean kinetic force was significantly different (it was maximum in 0.05% NaF followed by 0.2% NaF groups). Mirzaie et al. [12] showed that 0.018-inch SS wires had minimum friction, and round wires generated lower frictional force than rectangular wires. In their study, beta-TMA wire had maximum friction.

As discussed earlier, use of fluoride mouthwashes or other fluoride-containing prophylactic agents can change the oral environment. Although titanium and SS wires have a passive corrosion-resistant oxide layer on their surface, fluoride-containing products with a pH of 3.5 to 7 can damage this oxide layer. Resultantly, fluoride-containing products can lead to corrosion and discoloration and change the mechanical properties of orthodontic wires by damaging their superficial oxide layer. In acidic environments, small amount of fluoride can form hydrofluoric acid (HF) according to the following reaction: NaF+H=HF+Na. The formed HF can react with the passive oxide coating of SS alloys and degrade it according to the following reaction: Cr2O3+6HF=2CrF3+3H2O.

In our study, the SEM results were in agreement with the measured mean kinetic and static frictional forces. Wires immersed in 0.05% NaF had higher roughness and porosities than those in other groups. Also, the surface roughness and porosities of wires immersed in 0.2% NaF were greater than those of wires immersed in artificial saliva, which indicates the corrosion of SS and NiTi wires in presence of fluoride mouthwash and higher acidity of mouthwashes than artificial saliva. Similarly, Walker et al. [13] demonstrated changes in surface topography of NiTi and Cu-NiTi wires immersed in Phos-Flur® Gel solution with a pH of 5.1 (containing fluoride) and Prevident with a pH of 7. The changes were greater in wires immersed in Phos-Flur® Gel solution. Their results were in agreement with ours, showing that more acidic fluoride-containing solutions cause greater changes in surface topography of wires. The results of SEM qualitative assessment at x500 magnification were in agreement with the obtained mean values for the dynamic and static frictional forces. As noted in SEM micrographs, roughness and porosities of the wires immersed in 0.05% NaF were greater than wires immersed in 0.2% NaF and the control group (artificial saliva). Also, 0.2% NaF group showed higher surface roughness than the control group (artificial saliva), which may be due to the corrosion of SS and NiTi wires in fluoride mouthwashes and higher acidity of the mouthwashes than the artificial saliva. Huang [14] also indicated significant roughening and changes in surface topography of NiTi wires exposed to fluoride concentrations higher than 1700 ppm. Walker et al, [6] in another study reported that acidic pH of fluoride products can significantly degrade the oxide coating of titanium-containing alloys and change their surface topography. However, these changes also occur in neutral pH when the fluoride concentration is higher than 0.5%. Thus, aside from the pH, the concentration of fluoride is also a fundamental factor in degradation of the protective oxide coating and changing the surface topography. Our results regarding the frictional forces confirmed the SEM findings, indicating that the frequency of use of NaF mouthwash was more important than the concentration of fluoride. These findings were also in line with those of many other studies [8,15-19].

Future studies with longer follow-ups are required to obtain more reliable results. Also, studies are recommended to compare the cariostatic efficacy of 0.2% and 0.05% NaF mouthwashes in the clinical setting.

CONCLUSION

Within the limitations of this in vitro study, the results recommended the weekly use of 0.2% NaF mouthwash during the sliding mechanics to minimize frictional forces between the SS and NiTi wires and SS brackets.

CONFLICT OF INTEREST STATEMENT

None declared.

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