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Effect of Different Forms of Fluoride Application on Surface Roughness of Rhodium-Coated NiTi Orthodontic Wires: A Clinical Trial

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ABSTRACT

Objectives: This study aimed to assess the effect of different forms of fluoride application on surface roughness of rhodium-coated nickel-titanium (NiTi) orthodontic wires.

Materials and Methods: This randomized clinical trial was conducted on 15 patients randomly divided into three groups: toothbrush with Oral-B toothpaste only, Oral-B toothpaste, and daily mouthwash, Oral-B toothpaste, and sodium fluoride gel. The surface roughness indices of orthodontic wires including arithmetic mean height (Sa), root mean square height, root mean square gradient, developed interfacial area ratio (Sdr) and maximum surface height were measured by atomic force microscopy at baseline and after 6 weeks of application in the patients' mouths. Data were analyzed by paired t-test, ANOVA, Games-Howell, and Tukey-HSD tests ($P<0.05$).

Results: All surface roughness parameters in all three groups showed a significant increase after intervention, except for Sa in the toothpaste-only group ($P=0.057$) and Sdr in the sodium fluoride gel group ($P=0.064$).

Conclusion: The surface roughness of rhodium-coated NiTi orthodontic wires increases following the use of different forms of fluoride.

Keywords: Microscopy, Atomic Force; Orthodontic Wires; Fluorides

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INTRODUCTION

Nickel-titanium (NiTi) alloy is among the most common materials in orthodontic wires due to its favorable mechanical and clinical characteristics [1]. The most prominent features of NiTi wires are their spring back property and pseudo-elasticity, providing a wide range of low-force activation and deflection [2]. The demand for esthetics during orthodontic treatment has increased in recent years. The unesthetic aspect of orthodontic appliances is a significant concern for many patients, especially adults, who want to commence orthodontic treatment [3]. After introducing the tooth-colored brackets, archwires are the only metal part in the mouth. Despite the favorable mechanical properties of metal wires, the opaque appearance of these wires makes it difficult for adults to accept them [4].
The surface roughness of orthodontic wires can affect corrosion, friction, tooth movements, tissue compatibility, and esthetics [5]. On the other hand, there is a direct correlation between the amount of corrosion and surface roughness of these wires and the number of metal ions released into the oral cavity [6].

The surface roughness is a component of surface texture, which determines how the surface interacts with the environment, affecting the corrosion potential, biocompatibility, esthetics, friction, and plaque accumulation rate. Moreover, this feature is effective on color stability and appliance performance during sliding [7]. According to Kusy et al. [8] the surface roughness of wires is positively correlated with their coefficient of friction; however, frictional loss and orthodontic tooth movement are more complicated concepts, and several factors can affect them [9].

There are different ways to evaluate surface roughness, including contact surface profilometry, electron microscopy, laser spectroscopy, and also atomic force microscopy (AFM). Evidence has documented that, in most cases, there is a positive relationship between AFM, profilometry and laser spectroscopy [10]. Since AFM is capable of providing 3D information about surface morphology without damaging the specimen, it is nowadays considered as one of the most appropriate methods for surface topography evaluation [11].

Fluoride-containing materials are prescribed during orthodontic treatment because of the increased risk of caries due to the retentive nature of orthodontic appliances [12]. Many studies have shown the effects of fluoride mouthwash on surface properties of wires and brackets with an emphasis on increasing surface roughness and friction in the orthodontic system [13-15].

According to a study by Walker et al. [16] the oxide layer of alloys can be significantly affected by the concentration of fluoride, and this may impair its protective role. This superficial oxide layer prevents subsequent oxygen diffusion and induces corrosion resistance to stainless steel and beta-titanium wires. In another study, rhodium-coated wires immersed in acidulated phosphate fluoride (APF) gel showed the effects of pitting corrosion even beyond the coating into the underlying wire. Katić et al. [17] investigated the effect of immersing NiTi wires with different coatings, including rhodium coating in different fluoride compounds; the surface changes in the rhodium coating were more significant than the other types only in exposure to MI paste. Since the oral environment is exposed to a variety of physical and chemical factors and orthodontic treatments are usually performed over a long period of time, these materials may likely affect the surface properties of orthodontic appliances and wires. No clinical trials have been performed so far on the effect of fluoride on orthodontic wires. Thus, the present study aimed to compare the clinical effects of different methods of fluoride application on surface roughness of rhodium-coated NiTi wires.

MATERIALS AND METHODS

All procedures in this study were performed according to the guidelines of ethical standards of Babol University of Medical Sciences in Mazandaran, Iran, with the ethics code of MUBABOL.REC.1395.224. The study was registered in the Iranian Registry of Clinical Trials (IRCT20180102038190N1) as well. This randomized clinical trial was conducted on three groups, each including five patients aged 15–20 years who were capable of proper oral hygiene [18-20]. The exclusion criteria were poor oral hygiene, long-face patients, those with open-bite, use of specific mouthwashes or medications affecting the salivary flow, specific diseases affecting the salivary flow, smoking and alcohol consumption, previous extraction, or missing a tooth in the maxillary arch. The study objectives were explained to patients and their written informed consent was obtained.

Fifteen 0.016-inch rhodium-coated NiTi wires (GAC International, Bohemia NY) were cleaned with sterile gauze and saline to eliminate any debris. Wires with 2mm length were examined by AFM (Dual scopeTM DS 95 series; DME, Denmark) to record their baseline topography and to exclude the specimens with structural defects; images were taken from each specimen.

The Bass brushing technique [21] was taught to all patients and they were instructed to brush their teeth twice a day with a soft toothbrush and Oral-B fluoride toothpaste. The brackets (American Orthodontics, Sheboygan, WI) were bonded with 0.022×0.028-inch slot with the MBT system. For blind allocation of patients to the three groups, they blindly chose one card out of 15 cards on which the name of each group was written (5 cards for each group): (I) Oral-B fluoride toothpaste (Pro expert, Procter & Gamble UK, Weybridge, UK) as the control group, (II) Oral-B fluoride toothpaste +0.05% Oral-B fluoride daily mouthwash once a day at bedtime (15 mL each time), and (III) Oral-B fluoride toothpaste+APF gel (Sultan Topex APF, Sultan Dental Products, Englewood, NJ, USA) with 12300ppm 1.23% fluoride ions and a pH of 3.2 once during treatment using a tray for 1 minute according to the manufacturer's instructions.

The wires were ligated to the maxillary teeth of patients using elastomeric ties. After the treatment period (approximately 6 weeks), the wires were removed from the patients' mouth. Sterile gauze and saline were used to remove debris. Samples were tested by an operator who was blinded to the materials used in different groups (different types of fluorides) for surface roughness using the same method as described earlier, and the following parameters were evaluated [22]:

***Root mean square height (Sq)*:** which is defined as the root mean square of the surface irregularity value, z(x,y), on the intended surface.

***Arithmetic mean height (Sa)*:** is the height of the geometrical mean. It is also defined as the geometrical mean of the absolute values of the height within the surface.

***Root mean square gradient (Sdq)*:** For each of the x and y axis, the gradient of a surface point is estimated by oz=oy and oz=ox. Given the method below, the root means square gradient is then assessed for the entire surface.

$$Sdq = \sqrt{\frac{1}{A}\iint\left(\frac{\partial z}{\partial x}^2 + \frac{\partial z}{\partial y}^2\right)dxdy}$$

Where A is the definition area and z is the mean height of the surface on the definition area.

Developed interfacial area ratio (Sdr): it can be estimated as the average of the areas of two triangles made of 4 adjacent points. Sdr shows the surface complexity.

Maximum height of the surface (Sp): indicates the highest value of peak heights or, in other words, the zenith point across the whole surface. Sv characterizes the maximum pit height, which means the height of the lowest point on the surface [23]. Given the fact that the height is measured based on surface average, Sp and Sv values are always positive and negative, respectively. Absolute values of Sp plus Sv equal the Sz.

Paired t-test was used to compare the changes of surface roughness after intervention compared with baseline in all three groups. The mean differences in the variables before and after the experiment were compared among the three groups by ANOVA and pairwise by the Tukey's HSD and Games-Howell tests.

RESULTS

All samples showed an increase in surface roughness after the intervention. Figures 1 to 3 show the three-dimensional AFM images of archwires in different groups and their morphological changes.

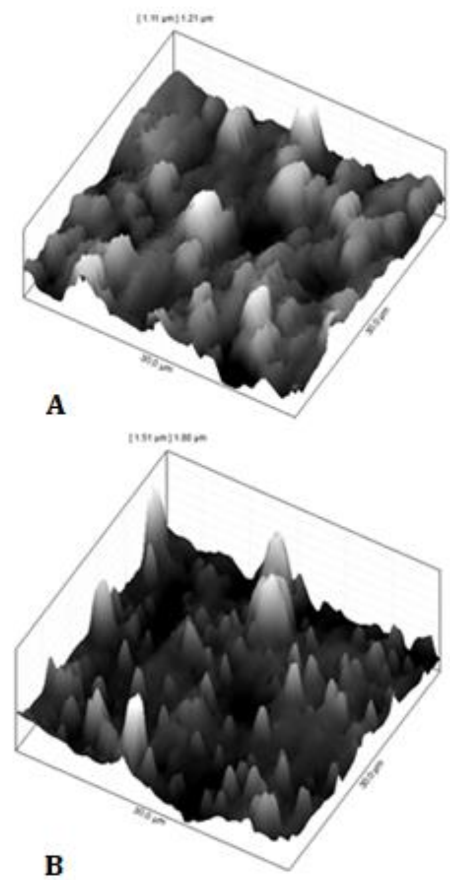

Fig. 1: Topographic AFM images (30×30 μm) before (A) and after (B) the intervention in group 1.

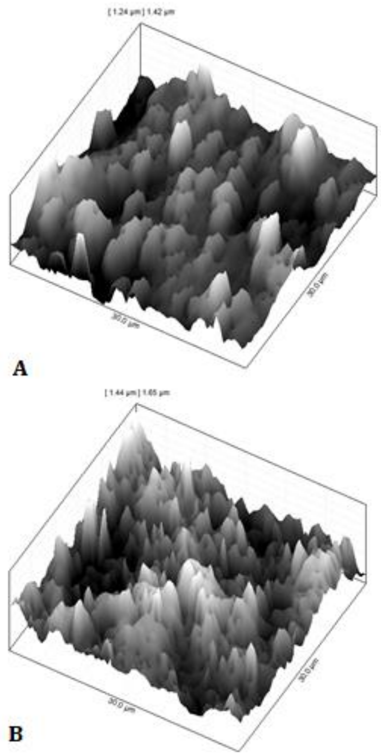

Fig. 2: Topographic AFM images (30×30 µm) before (A) and after (B) the intervention in group 2

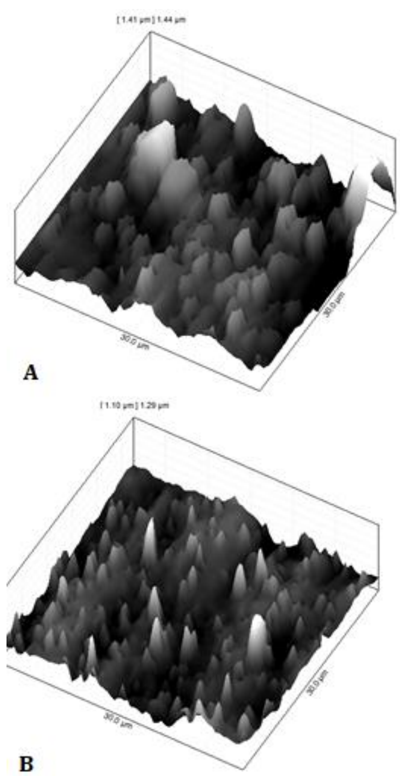

Fig. 3: Topographic AFM images (30×30 µm) before(A) and after (B) the intervention in group 3

The five parameters used to evaluate the surface roughness of the samples are shown in Table 1 as mean± standard deviation. After the intervention, Sa in groups that used toothpaste with gel (group 3) and toothpaste with mouth rinse (group 2) increased significantly (Table1; P=0.002) while in the toothpaste group, the change was not statistically significant (Table 1; P=0.057). Furthermore, the increase in Sa between groups 1 and 3 was not significant (P=0.0514) while the differences between groups 1 and 2 (P=0.001) and also groups 2 and 3 (P=0.007) were statistically significant (Table 2).

Regarding the Sq and Sdq, the increase in all three groups after the intervention was significant (Table 1; P<0.05). Differences in both Sq and Sdq before and after the intervention in groups 2 and 3 were significantly greater than those in group 1. However, the difference between groups 2 and 3 was not significant (Table 2).

For Sdr and Sz, the increase after the intervention was significant in all groups except group 3 (Table 1). Besides, the difference in the increase in Sdr and Sz among the groups was not statistically significant (Table 2).

DISCUSSION

Orthodontic wires may experience fatigue stress and corrosion during tooth movement [24]. On the other hand, corrosion has been shown to increase surface friction through the bracket-wire complex by increasing surface roughness [25]. Studies have also shown that surface roughness and surface friction in wires increase after being used in the patient's mouth [23,26]. Fais et al. [27] found out that brushing can change the topography and increase the surface roughness of titanium discs.

Based on our literature review, there was no clinical study so far on the effect of fluoride application on surface roughness of rhodium-coated NiTi wires. Therefore, this study aimed to clinically assess the effect of three types of fluoride prescriptions on surface roughness of rhodium-coated NiTi wires. We also considered the effects of confounding factors like saliva, brushing, and diet that may affect the surface roughness.

Table 1: Surface roughness of wires in different test groups before and after fluoride application

		Arithmetic mean height (µm)	Root mean square height (µm)	Root mean square gradient	Developed interfacial area ratio (%)	Maximum surface height (µm)
Group 1	Before	112.42±21.71	142.74±27.75	0.368±0.067	5.51±2.78	644.80±134.35
	After	138.49±40.99	177.01±27.04	0.479±0.09	7.57±2.41	871.24±83.15
	P	0.057	0.002	0.004	0.021	0.004
Group 2	Before	106.57±25.17	134.75±29.94	0.112±0.381	5.99±2.95	649.27±137.13
	After	183.74±23.12	187.51±37.27	0.655±0.233	9.39±2.095	811.76±195.9
	P	0.002	0.001	0.023	0.036	0.027
Group 3	Before	103.32±15.67	129.44±20.38	0.36±0.062	6.26±2.03	619.83±101.09
	After	195.42±33.42	199.44±40.79	0.719±0.167	13.15±7.61	883.90±130.89
	P	<0.001	0.006	0.004	0.064	0.002

Values represent mean± standard deviation of differences before and after the intervention.
Group1: toothpaste; group 2: toothpaste+ mouth rinse; group 3: toothpaste+ acidulated phosphate fluoride gel
P-values are the results of paired t-test comparing before and after intervention values in each group

Table 2: Comparison of differences in parameters before and after the intervention in the three groups

Parameter differences	Group 1	Group 2	Group 3	P
Arithmetic mean height (µm)	26.06±22.02^{a}	77.17±16.26^{b}	92.1±19.34^{b}	0.001*
Root mean square height (µm)	34.27±9.96^{a}	52.75±7.71^{ab}	69.99±30.04^{b}	0.044*
Root mean square gradient	0.111±0.04^{a}	0.27±0.12^{ab}	0.35±0.13^{b}	0.011*
Developed interfacial area ratio (%)	2.05±1.24	3.4±1.88	6.88±6.04	0.172
Maximum surface height (µm)	264.07±85.36	162.49±79.95	206.44±77.02	0.213

Values represent mean± standard deviation of differences before and after the intervention
Group1: toothpaste; group 2: toothpaste+ mouth rinse; group 3: toothpaste+ acidulated phosphate fluoride gel
Different superscripted letters (ab) represent statistically significant differences between two groups in each row of the table by the Tukey's HSD or Games-Howell post-hoc test
* Indicates a statistically significant difference based on analysis of variance

The findings of this study indicated that the values of Sa (except in group 1), Sq, Sdq, Sdr (except in group 3), and Sz parameters significantly increased in all groups after using different forms of fluoride compared with baseline. These changes mean that the surface roughness of the wires increased in experimented groups compared with before the intervention.

The surface coating of rhodium-coated wires is heterogeneous [28] and has defects where the underlying alloy is in contact with the environment. Due to the difference in the corrosion potential of the underlying alloy and the noble metals (gold and rhodium) in the surface coating, the corrosion rate of these wires may increase [29]. Augmentation of fluoride in the surrounding environment of NiTi wires reduces their corrosion resistance, which can cause corrosion [30]. Fluoride ions can also attenuate the protective effect of TiO2 layer on titanium and its alloys through the formation of Ti-F [31]. In acidic fluoride-containing environments, formation of hydrofluoric acid by the fluoride ions destroys the TiO_2 protective layer [28].

In the study by Katic and colleagues [17], rhodium-coated NiTi wires were more susceptible to corrosion than other wires after exposure to different fluoride prescriptions.

In the present study, surface roughness increased in all experimental groups after treatment, which could be due to surface corrosion. The superiority of the present study over the study by Katić et al. [17] is its clinical design. In vitro nature of their recent led to exclusion of the effects of confounding factors present in the oral environment, such as saliva [32], temperature changes, and brushing [27].

Alavi et al. [14] investigated the effect of fluoride on friction of metal brackets and wires. They concluded that the friction between stainless steel brackets and NiTi and steel wires is affected by higher fluoride concentration. The results of their study for lower fluoride concentrations are different from the present study. Studies have shown that there is a correlation between friction and surface roughness; moreover, friction is affected by force in wire-bracket combination, their angle of contact, surface properties of bracket, and some other factors [13,33]. Therefore, increased friction may not be observed despite the increase in surface roughness. They used stainless steel and NiTi orthodontic wires, but in the present study, rhodium-coated NiTi orthodontic wires were used, which could have different effects when comparing with non-coated wires. Huang [34] investigated the effect of fluoride solutions on different NiTi wires after 28 days of application and mentioned no significant difference in surface roughness of the wires in solutions containing less than 2500 ppm fluoride ions. However, a significant increase in surface roughness was seen at values over 2500 ppm. Contrary to their study, an increase in surface roughness was observed in experimental groups in the present study, which may be explained by the factors such as differences in surface coating of wires and corrosive agents present in the oral environment, brushing, and various foods consumed by patients, which were not present in the study by Huang [34] because of its in vitro nature.

In clinical application of these wires, it should be kept in mind that despite the esthetic improvements of orthodontic wires, they continue to have defects and show significant changes following use in the oral cavity.

We suggest investigation on the friction coefficient of wires before and after intervention and examination of saliva in terms of ion release from wires. Despite the relatively small sample size, which may be considered as a limitation of the present study, statistically significant differences were observed.

CONCLUSION

Within the limitation of this study, it was concluded that the surface roughness of rhodium-coated NiTi orthodontic wires increases after different methods of fluoride application in orthodontic patients.

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CONFLICT OF INTEREST STATEMENT

None declared.

REFERENCES

1. Andreasen GF, Hilleman TB. An evaluation of 55 cobalt substituted Nitinol wire for use in orthodontics. J Am Dent Assoc. 1971 Jun;82(6):1373-5.
2. Kusy RP. A review of contemporary archwires: their properties and characteristics. Angle Orthod. 1997;67(3):197-207.
3. Wang Y, Guo C, Zhou C, Fan M, Wang W, Lin J, et al. Influential factors of esthetic evaluation of mandibular prominence in orthodontic patients. Chin J Med Aesthet Cosmetol. 2018:46-9.
4. Kaur S, Singh R, Soni S, Garg V, Kaur M. Esthetic orthodontic appliances-A review. Ann Geriatr Educ Med Sci. 2018 Jan;5(1):11-4.
5. Nalbantgil D, Ulkur F, Kardas G, Culha M. Evaluation of corrosion resistance and surface characteristics of orthodontic wires immersed in different mouthwashes. Biomed Mater Eng. 2016 Nov 25;27(5):539-549.
6. Mikulewicz M, Wołowiec P, Loster BW, Chojnacka K. Do soft drinks affect metal ions release from orthodontic appliances? J Trace Elem Med Biol. 2015;31:74-7.
7. Sugisawa H, Kitaura H, Ueda K, Kimura K,

Ishida M, Ochi Y, et al. Corrosion resistance and mechanical properties of titanium nitride plating on orthodontic wires. Dent Mater J. 2018 Mar 30;37(2):286-292.
8. Kusy RP, Whitley JQ, Mayhew MJ, Buckthal JE. Surface roughness of orthodontic archwires via laser spectroscopy. Angle Orthod. 1988 Jan;58(1):33-45.
9. El-Bialy T, Alobeid A, Dirk C, Jäger A, Keilig L, Bourauel C. Comparison of force loss due to friction of different wire sizes and materials in conventional and new self-ligating orthodontic brackets during simulated canine retraction. J Orofac Orthop. 2019 Mar;80(2):68-78. English.
10. Dufrêne YF, Ando T, Garcia R, Alsteens D, Martinez-Martin D, Engel A, et al. Imaging modes of atomic force microscopy for application in molecular and cell biology. Nat Nanotechnol. 2017 Apr 6;12(4):295-307.
11. D'Antò V, Rongo R, Ametrano G, Spagnuolo G, Manzo P, Martina R, et al. Evaluation of surface roughness of orthodontic wires by means of atomic force microscopy. Angle Orthod. 2012 Sep;82(5):922-8.
12. Ren Y, Jongsma MA, Mei L, van der Mei HC, Busscher HJ. Orthodontic treatment with fixed appliances and biofilm formation--a potential public health threat? Clin Oral Investig. 2014 Sep;18(7):1711-8.
13. Khoury ES, Abboud M, Bassil-Nassif N, Bouserhal J. Effect of a two-year fluoride decay protection protocol on titanium brackets. Int Orthod. 2011 Dec;9(4):432-51.
14. Alavi S, Farahi A. Effect of fluoride on friction between bracket and wire. Dent Res J (Isfahan). 2011 Dec;8(Suppl 1):S37-42.
15. Bagatin CR, Ito IY, Andrucioli MC, Nelson-Filho P, Ferreira JT. Corrosion in Haas expanders with and without use of an antimicrobial agent: an in situ study. J Appl Oral Sci. 2011 Nov-Dec;19(6):662-7.
16. Walker MP, Ries D, Kula K, Ellis M, Fricke B. Mechanical properties and surface characterization of beta titanium and stainless steel orthodontic wire following topical fluoride treatment. Angle Orthod. 2007 Mar;77(2):342-8.
17. Katić V, Mandić V, Ježek D, Baršić G, Špalj S. Influence of various fluoride agents on working properties and surface characteristics of uncoated, rhodium coated and nitrified nickel-titanium orthodontic wires. Acta Odontol Scand. 2015 May;73(4):241-9.
18. da Silva DL, Mattos CT, Simão RA, de Oliveira Ruellas AC. Coating stability and surface characteristics of esthetic orthodontic coated archwires. Angle Orthod. 2013 Nov;83(6):994-1001.
19. Suárez C, Vilar T, Gil J, Sevilla P. In vitro evaluation of surface topographic changes and nickel release of lingual orthodontic archwires. J Mater Sci Mater Med. 2010 Feb;21(2):675-83.
20. D'Antò V, Rongo R, Ametrano G, Spagnuolo G, Manzo P, Martina R, et al. Evaluation of surface roughness of orthodontic wires by means of atomic force microscopy. Angle Orthod. 2012 Sep;82(5):922-8.
21. Verstrynge A, Van Humbeeck J, Willems G. In-vitro evaluation of the material characteristics of stainless steel and beta-titanium orthodontic wires. Am J Orthod Dentofacial Orthop. 2006 Oct;130(4):460-70.
22. Blateyron, F. The areal field parameters. Chapter 2; In Characterisation of Areal Surface Texture; Leach, R., Ed.; Springer: Berlin/Heidelberg, Germany, 2014.
23. Martha K, Ogodescu A, Bica CI, Varlam CM. Corrosion Behaviour and Surface Modification of Intra-orally Engaged Orthodontic Ni-Ti Wires. REV CHIM. 2017 May 1;68(5):1077-80.
24. Abbassy MA. Fluoride influences nickel-titanium orthodontic wires' surface texture and friction resistance. J Orthod Sci. 2016 Oct-Dec;5(4):121-126.
25. Pulikkottil VJ, Chidambaram S, Bejoy PU, Femin PK, Paul P, Rishad M. Corrosion resistance of stainless steel, nickel-titanium, titanium molybdenum alloy, and ion-implanted titanium molybdenum alloy archwires in acidic fluoride-containing artificial saliva: An in vitro study. J Pharm Bioallied Sci. 2016 Oct;8(Suppl 1):S96-S99.
26. Rongo R, Ametrano G, Gloria A, Spagnuolo G, Galeotti A, Paduano S, et al. Effects of intraoral aging on surface properties of coated nickel-titanium archwires. Angle Orthod. 2014 Jul;84(4):665-72.
27. Fais LM, Fernandes-Filho RB, Pereira-da-Silva MA, Vaz LG, Adabo GL. Titanium surface topography after brushing with fluoride and fluoride-free toothpaste simulating 10 years of use. J Dent. 2012 Apr;40(4):265-75.
28. Katic V, Curkovic L, Bosnjak MU, Peros K, Mandic D, Spalj S. Effect of pH, fluoride and hydrofluoric acid concentration on ion release from NiTi wires with various coatings. Dent Mater J. 2017 Mar 31;36(2):149-156.
29. Katić V, Curković HO, Semenski D, Baršić G, Marušić K, Spalj S. Influence of surface layer on mechanical and corrosion properties of nickel-titanium orthodontic wires. Angle Orthod. 2014 Nov;84(6):1041-8.

30. Heravi F, Moayed MH, Mokhber N. Effect of fluoride on nickel-titanium and stainless steel orthodontic archwires: an in-vitro study. J Dent (Tehran). 2015 Jan;12(1):49-59.
31. Lee TH, Huang TK, Lin SY, Chen LK, Chou MY, Huang HH. Corrosion resistance of different nickel-titanium archwires in acidic fluoride-containing artificial saliva. Angle Orthod. 2010 May;80(3):547-53.
32. Loveland K. Coated and Uncoated Nickel-Titanium Archwires: Mechanical Property and Surface Topography Response to a Simulated Oral Environment with and without Bracket-Related Load-Deflection Induced Stress [Master's Thesis]. University of Missouri-Kansas City; 2017.
33. Mane PP, Pawar R, Ganiger C, Phaphe S. Effect of fluoride prophylactic agents on the surface topography of NiTi and CuNiTi wires. J Contemp Dent Pract. 2012 May 1;13(3):285-8.
34. Huang HH. Variation in surface topography of different NiTi orthodontic archwires in various commercial fluoride-containing environments. Dent Mater. 2007 Jan;23(1):24-33.