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Evaluation of the effect of three mouthwashes on the mechanical properties and surface morphology of several orthodontic wires: An *in vitro* study

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Abstract

Background:

The aim of this study was to evaluate and compare the changes in the mechanical properties and surface morphology of different orthodontic wires after immersion in three mouthwash solutions.

Materials and Methods:

In this *in vitro* study, five specimens of each of 0.016 inch nickel titanium (NiTi), coated NiTi, and stainless steel orthodontic wires were selected. The specimens were immersed in 0.05% sodium fluoride (NaF), 0.2% chlorhexidine, *Zataria multiflora* extract, and distilled water (control) for 1.5 h at 37°C. After immersion, loading and unloading forces at 0.5 mm intervals and the elastic modulus (E) of the wires were measured using a three-point bending test. Surface changes were observed with a scanning electron microscope (SEM). Two-way analysis of variance and Bonferroni tests were used to compare the properties of the wires. The level of significance was set at 0.05.

Results:

Statistically significant changes in loading and unloading forces and E of the orthodontic wires were observed after immersion in different mouthwash solutions ($P < 0.05$). A pairwise comparison showed a nonsignificant difference between the effect of different mouthwashes on the E of different types of wires ($P > 0.05$). SEM images showed surface changes in some types ofthe orthodontic wires.

Conclusion:

The mouthwashes used in this study seemed to change the mechanical properties and surface quality of the orthodontic wires.

Key Words: Elastic modulus, mechanical processes, mouthwashes, orthodontic wire

INTRODUCTION

Currently, more adult patients are seeking orthodontic treatment, and there is an increasing demand for improvement in the esthetic quality of orthodontic appliances. This problem is partially solved by the introduction of esthetic brackets and coated wires.

One of the most important aspects of a successful orthodontic treatment is the maintenance of good oral hygiene and caries control. Compromised oral hygiene can lead to enamel demineralization and decay.[1,2] Orthodontists should recommend that patients regularly use the products containing fluorides, such as mouthwashes and gels, in addition to the daily use of fluoride toothpaste during orthodontic treatment to prevent tooth decay.[3] Fluoride mouthwashes are available in 0.05% and 0.2% fluoride concentrations that are prescribed daily or weekly by orthodontists to improve the level of oral hygiene during treatment.[4] Therefore, orthodontic wires can be continuously exposed to fluoride.

Using different mouthwashes and prophylactic agents containing fluoride can change the oral environment. Wires made of stainless steel (SS), titanium (Ti), and Ti alloys, such as NiTi and Ti molybdenum alloy, are high corrosion resistant because of having a protective oxide layer on their surfaces.[5] Different components of fluoride-containing agents by destroying this protective layer can cause corrosion,[5,6,7] discoloration,[6] and changing the mechanical characteristics of orthodontic wires.[2,5] The negative effects of fluoride ions on the coated wires were also recently mentioned in a few articles.[8]

Besides fluoride mouthwashes, antiseptic mouthwashes such as chlorhexidine (CHX) may be used by orthodontic patients to reduce plaque accumulation and pathogenic microorganisms.[9] A few articles are available about the impact of CHX mouthwash on orthodontic wires.[10,11]

The use of herbal mouthwashes by orthodontic patients has recently increased.[11,12,13,14] They are safer than other mouthwashes due to the lack of chemical components. One of the herbal mouthwashes is *Zatariamultiflora* extract (ZM). The main components of this herbal extract are phenolic compounds such as carvacrol, thymol, and eugenol.[15] To date, the effects of this mouthwash on orthodontic wires have not been investigated.

Due to the lack of studies of the effects of different mouthwashes on orthodontic appliances, the purpose of this *in vitro* study was to evaluate the potential effects of different mouthwashes on the mechanical and surface properties of orthodontic wires to find an appropriate mouthwash for use during orthodontic treatment.

MATERIALS AND METHODS

Three types of commercially available round orthodontic arch wires were investigated in this study. These wires included NiTi wire (MIB Co., Zhuhai, China), SS wire (Jiscop Co, Hansol Techno-Town, Korea), and a NiTi-coated wire (GAC, Sentalloy High Esthetic, Japan). Preformed maxillary 0.016 inch round wires were cut in 25 mm lengths from the straight posterior ends of the arch wires.

Based on the previous studies[5,6,8,11] and taking into account of 95% confidence level and 80% power for each type of the wire, five specimens in each testing group were prepared. 60 specimens were used in this study.

Three different mouthwash solutions were used. The solutions were 0.05% sodium fluoride (NaF) mouthwash (Oral-B, Germany), 0.2% CHX (Iran Najo Pharmaceutical Co., Tehran, Iran), and ZM extract (Barij Essence Pharmaceuticals Co., Kashan, Iran). Distilled water (DW) was used as control group. According to the different solutions mentioned, there were four major groups, and each of these groups was divided into three subgroups based on the three types of the wires in this study. Table 1 shows these different groups. The wires in each group were immersed in their respective solutions and incubated at 37°C for 1.5 h. This time was equivalent to 3 months of one1-minute daily application of these mouthwashes.[2,5,8] After this time, all the specimens were removed from the solutions and rinsed with DW.

Next, all the specimens were subjected to a three-point bending test on a universal testing machine (Hounsfield, Tinius Olsen Ltd., Honeycrock Lane, Redhill, UK) with a load cell of 50 KN [Figure 1]. For the three-point bending test, a jig with two parallel brass rods was mounted on the lower jaw of the machine [Figure 2]. Two GAC® (GAC International, Bohemia, NY, USA) edgewise central incisor brackets with a slot size of 0.022 × 0.028 inches were bonded on the top of these rods with an inter bracket distance of 15.5 mm, according to Wilkinson's standards.[16] This distance was selected to clinically simulate the distance between the middle of the central and canine brackets in a maxillary male dentition. The wires were placed in the brackets and fixed with elastomeric ligatures.

Compressive load was applied using the third rod that was vertically attached to the machine with a crosshead speed of 0.5 mm/min to the center of each wire. Each specimen was loaded up to a 2.5 mm deflection. Unloading force was applied at the same speed. Force in Newtons and deflection in millimeters were recorded for each specimen with a computer software program (Qmat, Tinius Olsen Ltd., Honey crock Lane, Redhill, UK). The mean magnitude of forces for each specimen were calculated in each 0.5 mm interval during loading and unloading.

Based on the load-deflection curve and the dimensions of the wires, the stress and the corresponding strain were calculated using the following equation, and the stress-strain diagram was drawn.[5]

The flexural stress $\sigma f = FL/\sigma R^3$

The flexural strain $\varepsilon f = 6Dd/L^2$

Where,σf was the stress in the outer fibers at midpoint (MPa), εf was the strain in the outer surface (mm/mm), *F* was the load at a given point on the load-deflection curve (*N*), *L* was the support span (mm), *d* was depth of tested beam (mm), *R* was the radius of the beam (mm), and *D* was the maximum deflection of the center of the beam (mm).

The loading modulus of elasticity (*E*) of each specimen was calculated from the linear portion of the stress-strain diagram. One wire from each group was randomly selected too bserve the surface morphology using a scanning electron microscope (SEM) (VEGA3 SB TESCAN, Libušinatřída, Czech Republic).

Statistical analysis

Statistical tests were done using PASW® version 17 (SPSS Inc., Chicago, IL, USA). A one-sample Kolmogorov–Smirnov (K–S) test was used to evaluate the normal distribution of the data. A two-way analysis of variance (ANOVA) was used to identify significant differences between the three types of arch wires immersed in four respective type of solutions and the effects of interaction among the variables. Mean values of the modulus of elasticity and the loading and unloading forces in each group were calculated. A Bonferroni paired comparison was used to compare the effect of different mouthwashes on wire types. $P < 0.05$ was defined to be statistically significant for all the tests.

RESULTS

The results of the K–Stest showed a normal distribution of the data ($P > 0.05$). The effects of the different solutions on the three types of wires and their mean elastic moduli are presented in Figure 3. The results of the two-way ANOVA showed that the fluoride treatment caused a significant reduction in E of the NiTi and SS wires and a significant increase in E of the coated wires ($P = 0.000$). The CHX mouthwash produced a statistically significant increase of E in the NiTi and coated wires and a significant decrease of E in the SS wires compared to the control group ($P < 0.05$). The ZM mouthwash significantly increased the E of the NiTi wires and reduced the E in the SS and coated wires ($P < 0.05$).

A pair wise comparison showed no significant difference between the effect of NaF and CHX mouthwash on the E of different types of wires ($P = 1$). The difference between the effect of NaF mouthwash and ZM mouthwash on the E of wire types was not significant ($P = 0.17$). The difference between the effect of DW and ZM on different types of wires was also not statistically significant ($P = 1$).

A two-way ANOVA was used for the effect of different mouthwashes on the wires and on the mean values of forces in different intervals during the loading and unloading. The results are presented in Tables 2–4. *P* values for all of the loading and unloading forces in all of the groups were 0.000. The load-deflection curve for the three subgroups of the control group (G1) is presented in Figure 4 as a sample.

The results of the representative SEM of the wires after immersion in their respective solutions are shown in Figure 5. The observations showed that some surface changes occurred in some groups. It seemed that the CHX and ZM mouthwashes increased the irregularities and pitting of the wire surfaces in the G3a and G4a groups (NiTi wires) compared with the control group. As compared to the DW control group, the ZM and NaF mouthwashes seemed to change the surface morphology of the coated wires (G4b and G2b), with more pitting. The fluoride treatment also caused some irregularities on the surface of the SS wires (G2c). The CHX mouthwash did not seem to change the surface of the coated and SS wires obviously. The surface of the SS wires was not evidently changed after immersion in the ZM mouthwash.

DISCUSSION

One of the disadvantages of orthodontic treatment is compromised oral hygiene that leads to enamel demineralization, white spots, and caries.[8] In addition, some patients may develop periodontal problems during orthodontic treatment and need different mouthwashes to reduce plaque accumulation; thus, the use of different mouthwashes during orthodontic treatment is advocated.

Stiffness is an important parameter in determining the mechanical properties of wires. The stiffness of orthodontic wires can be assessed using a three-point bending test,[8] which evaluates the load-deflection properties of a wire; those properties are considered the most important parameters in determining the biological nature of tooth movement.[17,18] The advantages of this test are good stimulation of clinical application,[17] reproducibility,[16] and providing information on the behavior of the wires when subjected to vertical and horizontal deflections.[5,18]

In general, the three-point bending tests produce load-deflection diagrams with upper loading and lower unloading curves. The force needed to engage the wire in the bracket is shown in the loading curve, and the force delivered to the teeth during the alignment stage of orthodontic treatment is represented by the unloading curve.[19] The vertical difference between the two curves is the combined effect of material hysteresis and the effects of friction between archwire and bracket.[19] The modulus of elasticity determines the elastic stiffness and the performance of orthodontic archwires.[20] Increased E values reflect stiffer wires.[21]

In the present study, we investigated the effect of fluoride mouthwash on the modulus of elasticity of coated wires and found that the use of fluoride agents cause a significant increase in E of coated wires. By contrast, Hammad *et al.*'s study[8] on the mechanical and surface properties of translucent composite wires after fluoride treatment found that fluoride therapy significantly decreased E in the composite wires in comparison with a DW control group.

The difference in our results might be attributable to the difference in types of esthetic wires. We used esthetic wires coated with an epoxy resin layer while Hammad *et al.*[8] used composite wires with a polymer for the matrix, reinforced with glass fillers. The difference in the types of fluoride agents could be another factor contributing to the different results. Those authors used acidulated phosphate fluoride gel (1.1%) while we used NaF mouthwash 0.05%, which differs in both acidity and fluoride concentration. The high acidity of the fluoride agent in their study could have had a deteriorating effect on the glass fillers, the matrix, and the mechanical properties of the wires. They reported surface damage of the coated wire after fluoride exposure.

Elayyan *et al.*[22] stated that in dry conditions, the 0.016 inchcoated wires produced significantly lower loading and unloading forces than uncoated control wires with the same nominal size. The authors were certain that this was due to the smaller diameter of the NiTi arch wires inside the coated wires, which compensated for the thickness of the coated layer; their position accords with the results of a study conducted by da Silva *et al.*[23] The results from our study are also in agreement with these studies although we tested our specimens after they were immersed in different solutions. We observed lower forces produced by coated wires in all intervals of loading and unloading with different mouthwashes, in comparison with NiTi wires.

A statistically significant reduction in NiTi wires elastic modulus following fluoride treatment was observed in this study, which is consistent with one former study[8] that reported fluoride ions in an acidic environment could form hydrofluoric acid that deteriorates the oxide layer on the surface of Ti-based orthodontic wires, causing corrosion, and changes in the mechanical properties of those wires. There was a statistically significant increase in the unloading forces of NiTi wires in all intervals of deflection compared with the control group in our study. This was in contrast with Ahrari *et al.*,[24] who reported a decrease in forces at 0.5 and 1 mm interval unloading deflections and no significant changes in unloading forces for 1.5, 2, and 2.5 mm intervals compared with an artificial saliva control group. They believed that reductions in unloading forces at lower deflections in the fluoride-treated group caused delayed tooth movement. The differences compared with our results might be the effect of different concentrations of the fluoride mouthwash used and the modification of the three-point bending test.

Huang[25] stated that agents containing low levels of fluoride, such as toothpastes, mouthwashes, or fluoride gels with <2500-ppm fluoride, had no significant effect on the morphology of NiTi wires, even after 28 days immersion. Similarly, the SEM images in our study did not reveal much change in the surface of NiTi wires compared with the control group, which might be related to the concentration of fluoride.

We concluded that fluoride treatment produced a statistically significant decrease in E of SS wires compared with the control group. This is in agreement with the results of two other studies,[2,8] which both reported that fluoride did not have any effects on E of multi strand SS wire. Those authors concluded that the presence of chromium and nickel in the composition of multi strand SS wire might aid corrosion resistance in that kind of wire.

The present study determined that 1.5 h immersion in 0.2% CHX mouthwash caused a significant increase in E of NiTi wires, all unloading forces, and some intervals during loading compared with control group. Omidkhoda *et al*.[11] studied the effects of three different mouthwashes on the load-deflection properties of NiTi wires and stated that 0.12% CHX mouthwash caused a significant reduction of loading force during 3mm deflection compared to the control group; we did not evaluate the 3mm interval of loading and unloading forces in our study. We also used 0.2% CHX, which may have an effect on the differences between Omidkhoda *et al*.'s[11] results and our own. The SEM images showed the surface destruction of NiTi wires following immersion in CHX, which may be a factor in the altered mechanical properties of this type of wire.

This mouthwash also caused a significant reduction in E of SS wires compared to the control group, increased forces at 0.5 and 1 mm intervals, and decreased forces at other intervals during loading. In addition, all the unloading forces were elevated except for the 2.5 mm deflection. Another earlier study[10] examined the effect of 0.2% CHX mouthwash on orthodontic wires, reporting that this mouthwash did not have any significant effect on arch wire surface roughness or the frictional resistance of SS and NiTi wires but had not evaluated load-deflection characteristics of orthodontic wires. 0.2% CHX caused a significant increase in E of coated wires in our study; this mouthwash also appeared to cause an increase in loading and unloading forces. No other study has investigated this issue.

To date, there have been no other reported studies of the effect of ZM mouthwash to date, there have been no other reported studies of the effect of ZM mouthwash on different properties of orthodontic wires while only one study has reported the antimicrobial effects of this mouthwash on contaminated elastomeric ligatures.[12] This study is the first of which we are aware to examine the effects of this mouthwash on orthodontic wires; it exhibited an increasing effect on E of NiTi wires and a decreasing effect on E of SS and coated wires.

We found that ZM mouthwash increased the loading and unloading forces in SS and NiTi wires. The loading forces were decreased in coated wires. SEM images indicated a surface change on both NiTi and coated wires. The effect of this mouthwash on orthodontic wires appears to be related to its composition and phenolic compounds such as carvacrol, thymol, and eugenol.[18] These components may destroy the superficial layers of NiTi and coated wires and therefore affect their mechanical characteristics.

In our study, 1.5-h protocol was used to immerse wires in different mouthwashes. This exposure time was equivalent to 3 months of 1 min daily application of these mouthwashes. In clinical situations, the exposure time might be different because the patients are asked to use the mouthwash daily for 1 min and are refrained from rinsing their mouths for at least 30 min there after.[8,24] Mastication and the oral environment might also have an effect on the layer of orthodontic wires, but this effect could not be evaluated in this *in vitro* study. We used different brands of orthodontic wires that were clinically available. Wires from different manufacturers although similar in composition, might have different surface roughness and mechanical properties. Additional studies are suggested to compare the properties of different brands of wires.

CONCLUSION

We concluded that:

1. All mouthwashes caused a significant decrease in the stiffness of SS wires
2. Fluoride treatment decreased the stiffness of NiTi wires while ZM and CHX increased its stiffness
3. Fluoride and CHX mouthwashes increased the stiffness of coated wires, but ZM reduced it
4. All mouthwashes changed the loading and unloading forces and surface morphology of different wires, which could have an impact on the mechanical properties of these wires during orthodontic treatment.

Limitation

Although we used SEM to evaluate the surface morphology of the wires, exact evaluation the actual two-dimensional surface topography was not possible in our study.

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Conflicts of interest

The authors of this manuscript declare that they have no conflicts of interest, real or perceived, financial or non-financial in this article.

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Figures and Tables

Table 1

Groups	Subgroups
G1(DW)	G1a: DW + NiTi wire
	G1b: DW + coated wire
	G1c: DW + SS wire
G2 (NaFmouthwash)	G2a: NaF + NiTi wire
	G2b: NaF + coated wire
	G2c: NaF + SS wire
G3(CHXmouthwash)	G3a: CHX + NiTiwire
	G3b: CHX + coated wire
	G3c: CHX + SS wire
G4(ZMmouthwash)	G4a: ZM + NiTi wire
	G4b: ZM + coated wire
	G4c: ZM + SS wire

DW: Distilled water; CHX: Chlorhexidine; ZM: *Zatariamultiflora* extract; NiTi: Nickel titanium; NaF: Sodium fluoride; SS: Stainless steel

Different experimental groups

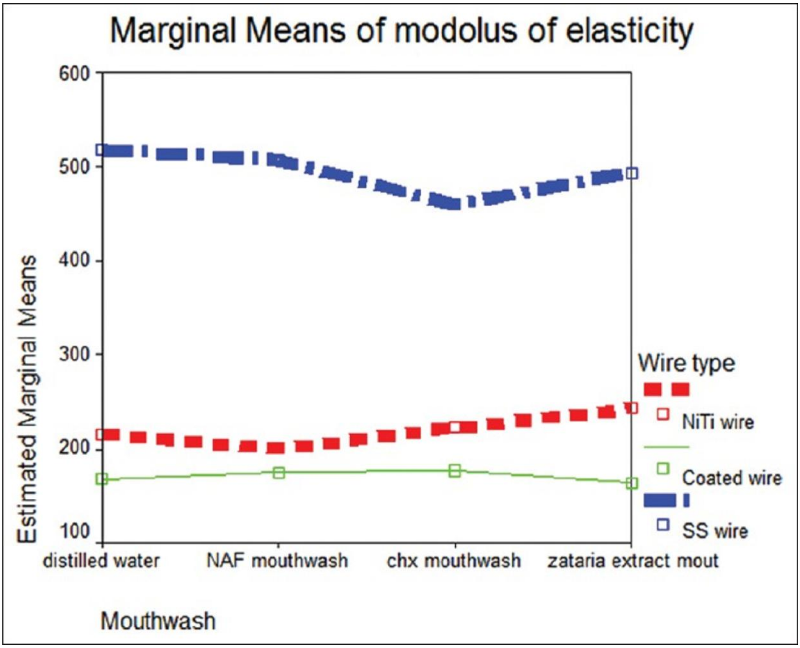
Figure 1

Three-point bending apparatus.

Figure 2

Close up view of the jig with two brass rods and brackets in place.

Figure 3



Mean elastic modulus of the studied wires after immersion in different solutions (GPa).

Table 2

Subgroup	Deflection				
	0.5 mm	1 mm	1.5 mm	2 mm	2.5 mm
NiTi + DW	1.9±0.12 (1.26±0.06)	3.25±0.07 (1.75±0.08)	3.93±0.06 (1.90±0.03)	4.56±0.05 (2.16±0.03)	5.35±0.12 (4.99±0.06)
NiTi + NaF	1.45±0.08 (1.31±0.02)	3.04±0.05 (1.92±0.05)	3.82±0.12 (2.12±0.08)	4.55±0.09 (2.49±0.06)	5.34±0.10 (5.31±0.07)
NiTi + CHX	1.79±0.13 (1.42±0.03)	3.24±0.04 (1.83±0.03)	4.14±0.10 (2.16±0.01)	4.65±0.09 (2.46±0.21)	5.38±0.07 (5.31±0.08)
NiTi + ZM	1.85±0.20 (1.48±0.04)	3.7±0.15 (2.47±0.01)	4.69±0.11 (2.70±0.00)	5.49±0.13 (2.92±0.03)	6.25±0.14 (6.10±0.15)

*All intervals of loading and unloading forces were significant at a *P*<0.001.DW: Distilled water; CHX: Chlorhexidine; ZM: *Zatariamultiflora* extract; NaF: Sodium fluorideNiTi: Nickel titanium

Mean and standard deviations of loading forces and unloading forces (in parentheses) in nickel titanium wires in different intervals (forces in Newton)*

Table 3

Subgroup	Deflection				
	0.5 mm	1 mm	1.5 mm	2 mm	2.5 mm
Coated NiTi + DW	1.36±0.06 (0.28±0.06)	2.42±0.08 (0.35±0.06)	3.14±0.09 (0.51±0.10)	3.83±0.12 (0.87±0.14)	4.54±0.26 (4.14±0.29)
Coated NiTi + NaF	1.32±0.10 (0.50±0.09)	2.49±0.07 (0.66±0.06)	3.02±0.14 (0.83±0.08)	3.57±0.11 (1.13±0.00)	4.32±0.17 (3.95±0.01)
Coated NiTi + CHX	1.5±0.04 (0.53±0.02)	2.6±0.10 (0.62±0.02)	3.20±0.10 (0.80±0.03)	3.93±0.21 (1.17±0.11)	4.35±0.08 (4.27±0.07)
Coated NiTi + ZM	0.99±0.01 (0.32±0.25)	2.26±0.03 (0.06±0.00)	2.80±0.04 (0.32±0.00)	3.41±0.03 (0.97±0.01)	4.05±0.03 (3.99±0.05)

*All intervals of loading and unloading forces were significant at $P<0.001$. DW: Distilled water; CHX: Chlorhexidine; ZM: *Zatariamultiflora* extract; NiTi: Nickel titanium; NaF: Sodium fluoride

Mean and standard deviations of loading forces and unloading forces (in parentheses) in coated nickel titanium wires in different intervals (forces in Newton)*

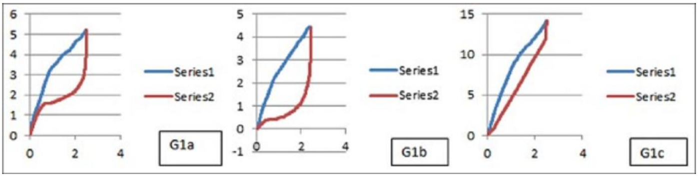
Table 4

Subgroup	Deflection				
	0.5 mm	1 mm	1.5 mm	2 mm	2.5 mm
SS + DW	4.41±0.10 (1.45±0.26)	8.06±0.05 (4.04±0.13)	10.73±0.19 (6.74±0.15)	12.58±0.08 (10.01±0.38)	14.98±0.12 (14.91±0.13)
SS + NaF	3.95±0.28 (1.09±0.05)	8.01±0.19 (3.46±0.12)	10.60±0.20 (5.83±0.41)	12.05±0.31 (9.30±0.17)	13.76±0.16 (13.71±0.21)
SS + CHX	4.47±0.08 (1.88±0.13)	8.12±0.02 (4.31±0.13)	10.62±0.07 (7.04±0.03)	12.32±0.07 (11.76±0.16)	14.45±0.06 (14.32±0.05)
SS + ZM	4.55±0.22 (1.75±0.99)	8.36±0.16 (4.40±0.08)	11.21±0.6 (7.01±0.8)	13.25±0.04 (11.73±0.02)	15.39±0.08 (15.12±0.08)

*All intervals of loading and unloading forces were significant at a $P<0.001$. DW: Distilled water; CHX: Chlorhexidine; ZM: *Zatariamultiflora* extract; NaF: Sodium fluoride; SS: Stainless steel

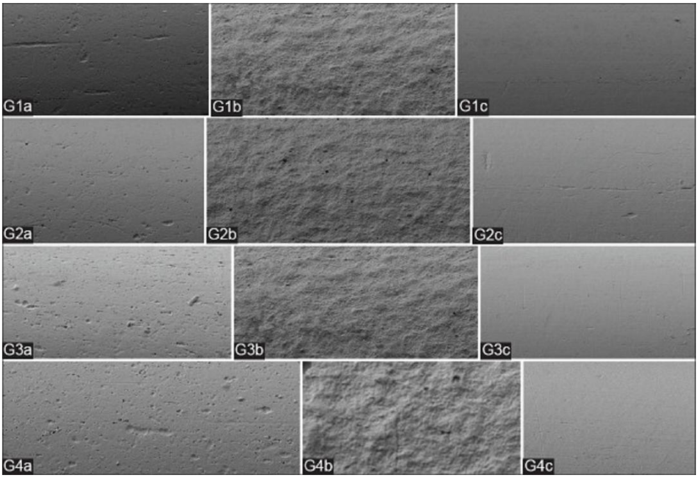
Mean and standard deviations of loading forces and unloading forces (in parentheses) in stainless steel wires in different intervals (forces in Newton)*

Figure 4



Load-deflection curve for three subgroups of control group (G1). (G1a: DW + NiTi wire; G1b: DW + coated wire; G1c: DW + SS wire).

Figure 5



Representative scanning electron microscope images of wire surfaces in different studied groups. (G1a: DW + NiTi wire; G1b: DW + coated wire; G1c: DW + SS wire; G2a: NaF + NiTi wire; G2b: NaF + coated wire; G2c: NaF + SS wire; G3a: CHX + NiTiwire ; G3b: CHX + coated wire; G3c: CHX + SS wire); G4a: ZM + NiTi wire; G4b: ZM + coated wire; G4c: ZM + SS wire).

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