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Effect of 0.05% Sodium Fluoride Mouthwash on Surface Roughness and Friction between Ceramic Brackets and Rhodium-Coated and Uncoated Stainless Steel Wires

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A B S T R A C T

Objectives: This study aimed to assess the effect of 0.05% sodium fluoride (NaF) mouthwash on the surface roughness and friction between ceramic brackets and rhodium-coated (RC) and uncoated stainless steel (SS) wires.

Materials and Methods: This experimental study was performed on 48 maxillary premolar ceramic brackets. Twenty-four pieces of RC-SS wires were used. Samples were divided into four groups. Groups 1 and 2 were immersed in artificial saliva, and groups 3 and 4 were immersed in a solution consisting of artificial saliva (9%) and mouthwash (91%). To assess surface roughness, images were obtained from the surface of wires and brackets with atomic force microscopy (AFM) and scanning electron microscopy (SEM) before and after the intervention. To assess friction, the wires were ligated into brackets, and friction was measured at a crosshead speed of 0.5 mm/minute using a universal testing machine. Data were analyzed using one-way analysis of variance (ANOVA) at the 0.05 significance level.

Results: Friction during sliding in RC wires was significantly less than that in SS wires ($P<0.05$). Increase in the friction in SS wires by mouthwash was significantly greater compared to RC wires ($P<0.05$). Surface roughness coefficients of the wires before the intervention were not significantly different. The surface roughness of the wires significantly increased after the intervention and it was greater in SS wires than in RC wires ($P<0.05$).

Conclusion: Considering the lower friction and surface roughness of SS-RC wires compared to SS wires, SS-RC wires may be a better alternative for use with ceramic brackets.

Keywords: Sodium Fluoride; Mouthwashes; Orthodontic Friction; Surface Properties; Orthodontic Wires; Ceramics; Orthodontic Brackets

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INTRODUCTION

In recent years, the demand for aesthetic orthodontic appliances has greatly increased. Thus, researchers have attempted to produce aesthetically favorable orthodontic appliances with acceptable clinical performance [1-3]. Application of aesthetic archwires with aesthetic brackets often results in the highest

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level of aesthetics in labial appliances [4]. Aesthetic archwires include composite archwires and metal archwires coated with polymers such as Teflon, epoxy resin, silver-polymer, rhodium, and less frequently, palladium [5,6].
Rudge et al [7] showed that coated archwires have variable coefficients of friction and surface roughness. Data regarding aesthetic archwires with the lowest coefficient of friction and surface roughness are controversial. In 2014, Kim et al [8] evaluated the surface topography of stainless steel (SS) archwires coated with rhodium and silver-polymer after sliding mechanics. Significant damage was noted on the surface of silver-polymer archwires, while SS and rhodium-coated (RC) archwires only showed slight depression on their surface, which was more severe in SS archwires [8]. In 2018, Asiry et al [9] reported that the surface roughness of RC archwires was not significantly different than that of nickel-titanium (NiTi) archwires but epoxy resin caused the greatest change in surface roughness compared to rhodium and NiTi.
At present, many orthodontists use sliding mechanics for the closure of extraction spaces. During sliding mechanics, biological tissue response and tooth movement only happen when the applied force overpowers the friction between brackets and archwires [10,11]. Evidence shows that about 50% of the load required for tooth movement is spent to overcome the friction force [12]. Excessive increase in friction force decelerates or stops tooth movement, decreases the effective force, and leads to loss of anchorage [10]. Therefore, the correct selection of brackets and wires for each patient is an important step in orthodontic treatment. These treatments change the normal oral ecology and increase the count of Streptococcus mutans in saliva and dental plaque. In patients at high risk of caries, mouthwashes are recommended in addition to mechanical cleaning of teeth [13,14]. Despite their beneficial effects, mouthwashes may change the mechanical and surface properties of archwires and brackets and increase the microhardness and friction [15]. Corrosion can significantly change the surface properties of metals as well [15]. Increased sliding friction between bracket and wire can occur due to the increased surface roughness of the wire, which leads to inappropriate load distribution in the orthodontic appliance and consequently decreased efficacy of guided movement of teeth along the archwire [15-17].
According to a study by Walker et al [18] in 2007, the concentration of fluoride can serve as an important factor in the failure of the protective oxide layer of alloys; this superficial oxide layer, which is eliminated by fluoride, prevents oxygen diffusion and confers corrosion resistance to SS and titanium molybdenum alloy (TMA) wires [18]. Many studies have evaluated the effect of fluoride mouthwash on surface properties of wires and brackets, particularly surface roughness and friction in fixed orthodontic systems [1,11,12,18,19].
Considering the high demand of patients for aesthetic orthodontic appliances and according to previous studies that have claimed that RC-NiTi archwires have less friction and surface roughness than NiTi archwires, this study aimed to evaluate the effect of sodium fluoride (NaF) mouthwash on the friction and surface roughness between ceramic brackets and uncoated and RC-SS wires.

MATERIALS AND METHODS

This study was performed on 48 maxillary premolar ceramic brackets (0.022×0.028-inch^2; standard edgewise, Dentsply GAC International, Islandia, NY, USA), 24 rectangular RC-SS wires (Dentsply GAC International, Islandia, NY, USA), and 24 rectangular uncoated SS wires (Dentsply GAC International, Islandia, NY, USA). The samples were divided into four groups of 12 samples as follows:
Group 1: RC archwires and ceramic brackets immersed in artificial saliva,
Group 2: SS archwires and ceramic brackets immersed in artificial saliva,
Group 3: RC archwires and ceramic brackets immersed in 0.05% NaF (0.05%; Colgate-Palmolive, São Paulo, Brazil),
Group 4: SS archwires and ceramic brackets immersed in 0.05% NaF.
The samples were cleaned with ethanol. Before the intervention, the final 5 cm of each archwire was cut at one end, and an image was taken from their surface using atomic force microscopy (AFM; Dualscope/Rasterscope C26, DME, Denmark). The mean roughness of each surface was determined quantitatively and qualitatively. Scanning electron microscopy (SEM; S4160, Cold Field Emission, Hitachi,

Japan) was used to take images of the surface of the brackets. For this test, eight brackets, two from each group, were chosen, and three images were taken from each bracket at ×50, ×100, and ×200 magnifications. The wires were then ligated into the brackets using elastic modules (O-ring, Dentaurum intraoral elastics, Dentaurum GmbH & Co. KG, Ispringen, Germany). Samples in the test (groups 3 and 4) and control (groups 1 and 2) groups were separately placed in 15-ml falcon tubes. The test tubes for the test groups were filled with a solution consisting of artificial saliva (9%) with the composition of NaCl (400 mg/l), KCl (400 mg/l), $CaCl_2.2H_2O$ (795 mg/l), $NaH_2PO_4.H_2O$ (690 mg/l), KSCN (300 mg/l), $Na_2S.9H_2O$ (5g/l), and urea (1000 mg/l), and 0.05% NaF mouthwash (91%). The test tubes for the control groups were filled only with artificial saliva. The samples were placed in their respective tubes and were incubated at 37°C for three hours. Next, the samples were transferred to a large beaker containing distilled water and were then placed inside a universal testing machine (Z250; Zwick/Roell, Ulm, Germany) for measurement of friction. For this purpose, the wires were placed in a custom-made fixture attached to the lower jig of the machine, and the bracket was attached to the upper jig using a custom-made device. Friction was measured at a crosshead speed of 0.5 mm/minute. For assessment of surface topography after the intervention, the same wires that had undergone AFM were evaluated for surface roughness, and the five following parameters were measured:

1- Sz (maximum height): this parameter is defined as the sum of the largest peak height and the largest pit depth within the defined area.

2- Sa (the extension of Ra (arithmetical mean height of a line) to a surface): this parameter expresses the difference in the height of each point as an absolute value compared to the arithmetical mean of the surface. This parameter is used to evaluate surface roughness.

3- Sq (root mean square height): this parameter represents the root mean square of ordinate values within the defined area and is equivalent to the standard deviation (SD) of the height.

4- Sdr (developed interfacial area ratio: this parameter is expressed as the percentage of the definition areas additional to the texture as compared to the planar definition area.

5- Sbi (the surface bearing index).

The brackets were gold-coated for SEM assessment and could not be used again; therefore, new brackets were used for the intervention. We used the Zwick test machine to measure friction. The computer set data as a chart in which the vertical axis shows friction (N), and the horizontal axis represents bracket movement (mm). Afterward, the highest rate of friction per minute was calculated. Superficial topography was assessed using Nova Imaging Analysis software (Nova Medical, Inc., Wilmington, MA, USA). Data were analyzed using one-way analysis of variance (ANOVA) at the 0.05 significance level.

RESULTS

Assessment of friction:

The type of wire and the type of media in which the samples were immersed had a significant effect on the friction between the wires and brackets. The friction created during sliding mechanics between the ceramic brackets and RC wires was significantly less than that of SS wires (P<0.05; Table 1).

Table 1. The mean, minimum, and maximum friction of the four groups

Group	Min	Max	Mean	SD
1	0.97	1.94	1.49	0.29
2	1.46	3.30	2.22	0.52
3	1.74	3.73	2.17	0.54
4	1.71	3.30	2.72	0.51

SD: Standard Deviation

NaF mouthwash significantly increased the friction in both groups (P<0.05) but this increase in the SS group was significantly greater than that in the RC group (P<0.05; Table 2).

Assessment of surface roughness:

The surface roughness of the wires before the intervention showed no significant difference between RC and SS wires (P>0.05). Comparison of Sz, Sa, Sq, Sbi, and Sdr showed that these parameters did not increase in the wires after immersion in artificial saliva and NaF mouthwash (P>0.05; Table 3). On the other hand, comparisons among Sz, Sa, and Sq showed that these parameters significantly increased in both wires after immersion in NaF mouthwash.

Table 2. Comparison of friction between the four groups

Group		Mean Difference	P value	95% CI Lower Bound	95% CI Upper Bound
1	3	-0.68	<0.001	-1.19	-0.15
	2	-0.73	<0.001	-1.25	-0.20
	4	-1.23	<0.001	-1.74	-0.70
2	1	0.06	<0.001	-0.46	0.57
	3	0.73	<0.001	0.20	1.25
	4	-0. 50	<0.001	-1.01	0.02
3	2	-0.68	0.07	-1.19	-0.15
	1	-7.30	<0.001	-1.25	-0.20
	4	-1.23	<0.001	-1.74	-0.70
4	1	0.50	0.03	0.02	1.07
	2	1.23	<0.001	0.70	1.74
	3	0.50	0.07	-0.02	1.01

SE: Standard Error, CI: Confidence Interval

Table 3. The surface roughness of rhodium-coated (RC) and uncoated stainless steel (SS) wires before and after the intervention

Wire			Minimum	Maximum	Mean	SD
SS	**Dry**	Sz	122	167	143.08	13.11
		Sa	9.09	34	20.12	7.56
		Sq	13.4	45.3	28.12	10.15
		Sdr	0.19	3.4	0.94	0.87
		Sbi	0.12	0.59	0.33	0.14
	NaF	Sz	427	621	515	57.23
		Sa	31.8	104	57.18	24.71
		Sq	51.5	127	77.46	25.25
		Sdr	1.28	8.3	2.79	1.85
		Sbi	0.02	0.59	0.26	0.15
	Artificial saliva	Sz	168	198	184.08	10.70
		Sa	15.2	33.7	26.5	5.59
		Sq	22.4	42.5	34.01	6.82
		Sdr	0.56	3.35	1.81	0.86
		Sbi	0.23	0.42	0.3	0.06
RC-SS	**Dry**	Sz	122	178	150.75	21.12
		Sa	10.1	34.7	21.27	7.48
		Sq	13.4	43.8	27.21	8.94
		Sdr	0.5	3.4	1.39	0.94
		Sbi	0.12	0.44	0.29	0.09
	NaF	Sz	214	310	250.33	31.98
		Sa	31.7	52	40.62	6.99
		Sq	21.2	65.8	49.01	11.79
		Sdr	1.57	8.6	2.99	2.02
		Sbi	0.22	0.47	0.34	0.07
	Artificial saliva	Sz	124	198	165	21.74
		Sa	17.9	38.7	26.86	5.41
		Sq	23.8	38.4	32.97	4.99
		Sdr	0.38	2.14	1.18	0.60
		Sbi	0.15	0.38	0.25	0.08

SD: Standard Deviation; RC-SS: Rhodium-Coated Stainless Steel; NaF: Sodium Fluoride; Sa: Arithmetical Mean Height; Sz: Maximum Height; Sq: Root Mean Square Height; Sdr: Root Mean Square Surface Slope, Sbi=Surface Bearing Index

Table 4. Comparison of surface roughness parameters for uncoated stainless steel wires before and after intervention

Group			Mean Difference	P value	95% CI Lower Bound	95% CI Upper Bound
Sz	Dry	Naf	371.92	<0.001	337.39	406.43
		Artificial saliva	41	0.17	75.52	86.47
	Naf	Dry	371.05	<0.001	337.39	406.43
		Artificial saliva	330.91	<0.001	296.39	365.43
	Artificial saliva	Dry	41	0.17	75.52	86.47
		NaF	330.9	<0.001	296.39	365.43
Sa	Dry	NaF	371.06	<0.001	21.72	52.38
		Artificial saliva	41	0.56	8.94	21.71
	Naf	Dry	37.06	<0.001	21/72	52.38
		Artificial saliva	30.68	<0.001	15.34	46.00
	Artificial saliva	Dry	6.39	0.56	8.94	21.71
		NaF	30.68	<0.001	15.34	46.00
Sq	Dry	NaF	49.34	<0.001	33.11	65.57
		Artificial saliva	5.89	0.65	10.33	22.12
	Naf	Dry	49.34	<0.001	33.11	65.57
		Artificial saliva	30.68	<0.001	27.21	59.68
	Artificial saliva	Dry	5.89	0.65	10.33	22.12
		NaF	30.68	<0.001	27.21	65.57

SE: Standard Error; CI: Confidence Interval; NaF: Sodium Fluoride; Sa: Arithmetical Mean Height; Sz: Maximum Height; Sq: Root Mean Square Height

Table 5. Comparison of surface roughness parameters for rhodium-coated stainless steel wires before and after intervention

Group			Mean Difference	P value	95% CI Lower Bound	95% CI Upper Bound
Sz	Dry	Naf	99.58	<0.001	74.09	125.07
		Artificial saliva	14.25	0.3	11.24	39.74
	Naf	Dry	99.58	<0.001	74.09	125.07
		Artificial saliva	85.33	<0.001	59.8	110.8
	Artificial saliva	Dry	14.25	0.3	11.24	39.74
		NaF	85.33	<0.001	59.8	110.8
Sa	Dry	NaF	19.35	<0.001	12.6	26.6
		Artificial saliva	-5.59	0.11	1.11	12.2
	Naf	Dry	19.35	<0.001	12.6	26.6
		Artificial saliva	13.76	<0.001	7.05	20.4
	Artificial saliva	Dry	5.59	0.11	1.11	12.2
		NaF	-13.76	<0.001	7.05	20.4
Sq	Dry	NaF	21.8	<0.001	12.7	30.8
		Artificial saliva	5.76	0.27	3.2	14.79
	Naf	Dry	21.8	<0.001	12.7	30.8
		Artificial saliva	16.04	<0.001	7.00	25
	Artificial saliva	Dry	5.76	0.27	3.2	14.79
		NaF	16.04	<0.001	7.00	25

SE: Standard Error; CI: Confidence Interval; NaF: Sodium Fluoride; Sa: Arithmetical Mean Height; Sz: Maximum Height; Sq: Root Mean Square Height

However, NaF caused significantly higher surface roughness compared to artificial saliva. This increase was significantly greater in SS wire compared to RC wire ($P<0.05$; Tables 4 and 5). Comparison of Sbi and Sdr showed that these parameters were not significantly different between SS and RC wires before and after the intervention ($P>0.05$; Table 3).

DISCUSSION

Evidence shows that the constituents of brackets and wires, surface roughness, hardness, the cross-section of the wire, modulus of elasticity, and different ligation methods are important factors influencing the friction created during orthodontic treatment [20,21].

The material of the wire and bracket is another factor affecting the friction. Previous studies have reported a lower coefficient of friction for fully coated archwires compared to labially coated archwires.

One possible reason is the loss of 25% of the coating during the course of treatment in labially coated archwires. This would increase the surface roughness and friction during sliding mechanics. Another reason mentioned in studies is the greater thickness of labially coated archwires compared to fully coated wires as the manufacturer decreases the dimensions of the archwire's base in fully coated wires to compensate for the thickness of the coating. However, this compensation is not performed for labially coated archwires. This would increase the size of the archwire and subsequently the friction. In general, the thickness of coating varies in different brands and is averagely 0.3 to 0.6 mm in fully coated and 1 to 1.4 mm in labially coated archwires [22]. Many studies have evaluated the friction of different types of orthodontic archwires in artificial and natural saliva. There are controversies regarding friction in wet and dry environments. In the oral environment and in the presence of saliva, loads and the coefficient of friction may decrease, increase or remain unchanged depending on the archwire alloy used during treatment [23,24]. TMA archwires have different coefficients of friction in wet and dry environments. Their dynamic coefficient of friction in a wet environment decreases by 50% of the value in a dry environment and becomes equal to the coefficient of friction of NiTi wires. However, it is still higher than the coefficient of friction of SS wires. According to these findings, the friction of wires in artificial saliva remains unchanged or increases [24]. This is especially true for SS, NiTi, and TMA wires but the friction of cobalt-chromium archwires decreases in the presence of artificial saliva [25]. We used artificial saliva in this study because, in most in-vitro studies on friction, artificial saliva is considered as the basic medium.

Type of ligation is another factor affecting friction. In a study by Natt et al [26], the rate of static friction was lower with elastic modules and higher with SS ligatures. In this study, we used elastic modules for attachment of wires and brackets because they allow the generation of a uniform elastic force when fitting the elastic around the bracket wings. Also, they minimize rubbing of wire surface against the bracket, which would compromise the results. In addition, the load created by using SS ligatures could not be controlled or standardized. Elastic modules eliminate the effect of corrosion of SS ligatures on the samples and consequently the friction.

Another important factor is the difference in the speed of sliding. Laws of friction state that friction is independent on the sliding speed. However, by an increase in sliding speed, the friction decreases in cobalt-chromium wires and increases in TMA wires [27]. Kim et al [8] evaluated the sliding resistance at a crosshead speed of 5 mm/minute for round RC-NiTi wires, rectangular RC-SS wires, and self-ligating ceramic brackets. NiTi and SS wires with similar conditions were used as the control group. They showed that coated wires had friction equal or slightly higher than that of the control wires [8]. The reason for this difference may be the higher sliding speed compared to our study. In fact, RC wires may have a behavior similar to that of TMA wires and may create greater friction by an increase in the speed of sliding.

Evidence shows that the use of 1.5 mm/minute and 0.5 mm/minute sliding speeds does not make a significant difference in the results. Selection of 5 mm/minute speed in studies, although optional, saves time [28]. In this study, we tried to select a sliding speed as low as possible (0.5 mm/minute) to obtain more accurate results although it may be time-consuming.

One of the drawbacks of orthodontic treatment is difficulty in oral hygiene maintenance, which can lead to enamel demineralization, white spot lesions, and caries. For this reason, daily use of

0.05% NaF mouthwash during orthodontic treatment is recommended to prevent caries [29]. Geramy et al [30] showed that 0.05% NaF increases the friction of NiTi, SS, and TMA wires. Alavi and Farahi [31] demonstrated that the topical application of fluoride significantly increases friction. We used Colgate NaF mouthwash in this study, and our findings confirmed those of previous studies since friction significantly increased after the intervention.

In 2018, Katić et al [32] stated that Mirafluor gel increases the corrosion resistance of RC archwires due to the high percentage of hydrofluoric acid in its composition, while MI Paste Plus has the lowest concentration of hydrofluoric acid and increases the surface roughness of RC wires.

The results of studies on the correlation between surface roughness and friction are controversial [33-35]. Some researchers supported this association [12], while some others found no significant correlation between these two parameters [36,37]. Since no systematic review or meta-analysis was found on this topic, a definitive decision cannot be made in this respect. On the other hand, studies on surface roughness and friction have used different wires, brackets, and in-vitro conditions with variable methodologies.

We used AFM to assess the surface roughness of the wires. Before the intervention, the surface roughness of the archwires was not significantly different but after immersion in Colgate NaF mouthwash, surface roughness significantly increased in both groups. However, the surface roughness of RC archwires was less affected than that of SS archwires.

In a review study in 2014, Totino et al [5] showed that titanium aluminum nitride-coated, tungsten carbide/carbon-coated, and diamond-like carbon-coated archwires were more resistant to corrosion following the use of fluoridated mouthwashes and toothpastes, which are commonly used by orthodontic patients. In our study, the surface roughness coefficients of the wires were not significantly different before the intervention. However, after the intervention, the surface roughness of the SS wire was significantly higher than that of the RC archwire. Thus, it may be concluded that the rhodium coating protects the surface of SS archwires against the effects of NaF mouthwash. However, this protective effect is not related to rhodium; it is attributed to the gold noble alloy which is used in combination with rhodium for coating of metal archwires. The gold noble alloy reacts less with external factors, such as NaF mouthwash, compared to nickel and other constituents of SS archwires [34].

CONCLUSION

It can be concluded that RC wires have lower friction with ceramic brackets compared to SS wires. According to the results of the present study, the use of RC-SS wires with ceramic brackets can be a better option for orthodontic patients with aesthetic demands.

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CONFLICT OF INTEREST STATEMENT

None declared.

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