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Assessment of the influence of metal ions released from the fixed orthodontic appliances on the static friction and surface topography of stainless steel and I archwires: An *in-vitro* study

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Abstract

BACKGROUND: Static friction force between the orthodontic brackets and wire impacts the sliding mechanics that affect teeth movements and treatment duration. This sliding media is jam-packed with released metal ions from the fixed appliances. This study aimed to assess the static frictional force and surface topography of stainless steel (SS) and I archwires in dry conditions and in media fully with metal ions that were released from fixed appliances.

METHODS: In this research study, a set of 60 as-received straight archwires specimens (5 cm wire) were employed and categorized into two groups based on the material type [30 super elastics new I archwires gauge (0.018 × 0.014 inch) and 30 SS archwires 0.018 × 0.022” as a control]. The archwires’ static friction force was measured while sliding a loaded Roth SS brackets (0.018”) on the archwire using a universal tensile testing machine in dry and metal ions released media, while the surface topography was assessed using a noncontact AFM machine.

RESULTS: The static friction of I archwire was significantly lower than the SS wire in dry condition. Metal ions media released from fixed appliances significantly reduced the Static friction compared to dry and wet conditions with deionized water for both wires. An Atomic Force Microscope machine surface roughness reports revealed that the highest mean of all three roughness parameters was found in the SS group, followed by I archwires in descending order. Additionally, metal ions media significantly reduce all roughness parameters.

Keywords:

Orthodontic brackets, sliding mechanics, static friction force, surface roughness parameters

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Introduction

Sliding mechanics is a commonly utilized approach in orthodontic treatment that involves the movement of teeth as the bracket glides over the archwire. Nevertheless, the friction produced at the combination archwire and the bracket can impede the intended orthodontic tooth movement, which is a significant disadvantage of this technique.[1] The level of friction that arises from this technique poses a clinical challenge to orthodontists since high friction levels can hinder the mechanics’ effectiveness and tooth movement efficiency. It could also complicate anchorage control.[2,3] Frictional resistance can result in a considerable loss of applied force, ranging from 12% to 60%.[4] Two forces are generated when two surfaces slide against each other: the Frictional Force tangent to the contact Surface and the Normal Force

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perpendicular to the Frictional Force and the contact Surface.[2] Two primary types of frictional forces have been identified: static friction and kinetic friction.[5] The static frictional force is the minimum force required to initiate movement between two stationary solid bodies. In contrast, kinetic friction represents the force preventing a solid object from sliding against another solid object at the same speed.[6] The significance of static friction outweighs kinetic friction, given that it presents greater resistance to change an object's position on a surface than maintaining its movement as opposed to other surfaces.[5]

During orthodontic tooth movement, the interaction between the archwire and the bracket or ligating ligature results in static and kinetic friction, contributing to only a part of the total resistance to sliding[4] classified the resistance sliding phenomenon into three components, namely, classic friction, binding, and notching, expressed as RS = classic friction + binding + notching. Controlling the classical friction (FR) in orthodontic treatment is imperative for ensuring repeatable sliding mechanics and determining the precise amount of orthodontic force exerted on the periodontium. Identified three major types of friction: FR, resulting from conventional ligation where the archwire compresses against the bracket slot's base; binding, which arises due to excessive archwire deformation, causing interlocking of the bracket and archwire and hindering tooth movement; and notching, which results from increased archwire deformation, leading to archwire and bracket interlock.[6] The direction of tooth movement during fixed orthodontic treatment is affected by the type and method of ligation utilized to secure the archwire within the bracket slot.[7] Stainless steel ligatures and elastomeric modules are commonly employed for ligation purposes. Studies have revealed that SS ligatures offer enhanced archwire-to-bracket slot stability, lower friction, and a slower force decay rate than elastomeric modules.[8]

In orthodontics, the friction experienced during sliding is influenced by various factors, including the type of bracket (conventional or self-ligating), ligating force, archwire-to-bracket angulation, slot and wire dimensions and shape, repeated bracket usage, and environmental conditions such as dryness and deionization.[9-11] A study investigated lubrication's influence on the frictional forces between brackets and NiTi archwires with rounded cross-sections.[12] The study revealed that frictional forces in an artificial saliva (wet) environment were more significant than in a dry environment.[13]

Additionally, rectangular wires exhibit greater frictional force than round wires, which may be due to their larger surface area. Additionally, wire size plays a role in frictional force, with smaller wires experiencing less friction than larger wires, as they have less contact with the bracket.[14] The study aimed to compare the friction levels generated by diverse types of orthodontic wires. The study outcomes showed that Elgiloy and NiTi wires generate higher friction than SS wires but to a comparable extent. At the same time, titanium molybdenum alloys (TMA) produce the highest amount of friction.[15]

Multiple studies have been conducted indicating that SS archwires have a smoother surface than TMA archwires.[16,17] Scanning electron microscopy analysis revealed that TMA wires possess uniformly distributed pores across their entire surface. The surface roughness of materials is crucial due to their impact on surface contact area, corrosive behavior, and material biocompatibility.[18] The surface roughness of orthodontic appliances plays a critical role in ion release, as exposure to the oral environment can increase corrosion and ion release.[19] Moreover, according to a study, the composition of the alloy utilized in the appliance can affect the number of metal ions released, with nickel ions being released at higher levels than other metal ions from fixed orthodontic appliances.[20] Furthermore, the study indicated that the concentration of nickel and chromium in saliva was the highest one week after appliance placement and gradually decreased over time.[21]

The I-arch system is a unique and innovative orthodontic archwire system. The I-arch orthodontic approach is biological, highly effective, and easily compatible. Rectangular archwires with immediate torque delivery are used starting at the alignment and leveling stage, giving the system effectiveness. It works well with any straight-wire prescription. Its biological compatibility is ensured by using gentle forces (starting at 23 g), which reduce orthodontic treatment's traumatic effects and pain, particularly at the start. Reduced bone damage, primarily at the vestibular cortical level. Chair time was reduced, and the number of arch wires per treatment was reduced.[22]

According to our knowledge, no previous study was conducted to evaluate the friction of the newly introduced archwire (I archwire) in dry, deionized, and ionized media released from fixed orthodontic appliances. This study evaluated the static friction and surface topography of a newly introduced I archwire (superelastic NiTi) in dry, deionized ionized media from the metal released from fixed orthodontic appliances to simulate the oral environments during orthodontic treatments.

Materials and Methods

Samples material description for UTM*(Assessing static)

The study used 60 as-received straight archwire specimens, each measuring 5 cm, which were divided into two groups based on material type: 30 super-elastic new I arch wires, gauge 0.018 × 0.014 in (SIA Orthodontic, Italy), and 30 SS archwires, gauge 0.018 × 0.022 in (SIA Orthodontic, Italy). The arch wires' static friction was assessed by sliding a SS Roth 0.018" bracket (Dentaurum, Isprengen, Germany) over them utilizing a universal tensile machine testing (GESTER, GT-UA03) with a custom-designed oral texture simulation template. The measurements were conducted at room temperature (22° C), with the 0.018 × 0.022" SS archwires serving as the control group and the super-elastic new I archwires (0.018 × 0.014") as the test group. A total of 60 Roth SS brackets (Dentaurum, Isprengen, Germany) for the maxillary right bicuspid (0.018 × 0.030" slot dimension) were used to slide over the arch wires, which were ligated to the bracket slots using gauge 0.010" SS ligature wires (Dentaurum, Germany). The tests were conducted dry at zero tipping with torque (-7) using a universal testing machine. The same examiner performed all samples and testing procedures, with each trial utilizing a new bracket, archwire segment, and SS ligature wire to prevent bias.

UTM* *Universal Tensile Machine, SS* Stainless Steel*

Experimental setup for UTM

The methodology utilized in this investigation draws upon established techniques for measuring friction.[23] It involves the application of a singular, equivalent force to the root's resistance center to simulate the forces experienced by tooth roots.[24] Before testing, all specimens were treated with an acetone solution to eliminate dust particles and residual oil layers from their surfaces.

The static friction between the bracket and archwire was assessed using a custom-made apparatus comprising a rigid metal baseplate in a vertical orientation, simulating a hemi-fixed appliance. Four Roth SS 0.018-inch brackets were bonded to the metal baseplate utilizing top X adhesive (Epoxy Steel Company, USA), applied to the bracket base. The movable bracket was positioned on the metal baseplate surface and pressed under a standard force of 500 gm[25] at 8 mm spacing with a 16 mm space allotted for the movable bracket. The archwire samples were inserted into the slots (0.018") of the brackets on the metal baseplate, and the archwire in two terminals was bent to avoid slipping during the test. The fixed brackets were secured to the archwire within the slot by SS ligature wires that were tied (2.2 mm 13 twistings) using a Mathew needle holder (Dentarum, Germany).[23] To investigate the effect of ionized and deionized water on frictional forces, water was extracted from an orthodontic appliance's immersion in deionized water (as described below). For the frictional tests, the extracted water was applied to the bracket and archwire sample using a disposable needle and syringe.[13]

A movable SS bracket with a 10 mm power arm was utilized to replicate the effect of a single equivalent force playing at the center of resistance of a first premolar tooth. The power arm held weights (100) gm, and a powerful SS round wire with a diameter of 0.9 mm/0.036 inches (Dentarum company) was employed for the experiment.[23] The bracket was moved at a rate of 5 mm/min across the central space for a distance of 5 mm, and load cell readings were obtained to determine the clinical force of retraction applied to the tooth.[23]

The UTM software measured the static and kinetic frictional force resistance between the bracket/wire. The XY graph generated by the software represented the movement of the bracket in millimeters/second (mm/s) on the X-axis and the frictional resistance force in Newtons (N) between the bracket/archwire on the Y-axis. The maximum frictional resistance force was recorded and converted to grams using the equation: friction in g = friction in (N) ÷9.8 × 1000.[26] The static frictional force was determined by identifying the peak forces encountered during the first millimeter of wire displacement in the load-displacement graph.[27]

To test under ion and deionized media, ion and deionized water were continuously dropped onto the bracket and archwire sample using a needle and syringe.[13] The friction force in Newton was determined as the difference between the load cell reading/the load on the power arm. All samples, which included 20 samples tested in dry, deionized, and ionized conditions, were measured at a room temperature of 22C°. Each test (for each bracket-arch wire and ligature combination) was repeated 10 times using a new as-received archwire, bracket, and ligature sample.

AFM (Atomic Force Microscope)

Sample description for AFM

Two types of archwire were used in the dry, deionized, and ionized conditions, one of which was considered the control (30) SS archwire, 0.018 × 0.022-inch dimension (SIA Orthodontic Rocca D'Evandro, Italy), and the other was the new type (30 no. superelastic NiTi I archwire, 0.018 × 0.014 inch, SIA Orthodontic, Rocca D'Evandro, Italy) to be tested in one type of bracket (ROTH Stainless steel bracket for Dentaurum, Isprengen, Germany). Surface topography measurements for each archwire were obtained using the Naio AFM Nanosurf microscope (Switzerland). The microscope employed noncontact scanning techniques to evaluate the 3D surface configuration and roughness.

Experimental setup for AFM

Three 5 mm samples were obtained from three different preformed archwires at the region where the bracket moves along the wire to analyze nearly straight specimens. Subsequently, the samples were affixed to a metal holder using fast-drying cyanoacrylate glue and observed under ambient conditions using a Naio AFM Nanosurf microscope (Switzerland) operating in noncontact mode. Sixty random areas (15 × 15 mm) on the surface were analyzed for each specimen, totaling 180 data points. The roughness parameters, including RA, RQ, and Mh, were recorded after processing the three-dimensional images with Mountains 9 software. The analysis employed AFM probes (curvature radius <10 nm) mounted on cantilevers (250 nm) with a spring constant of 0.1 N/m.

Wet media (Ionized and deionized) setup (Sample description and Experimental setup)

This experiment used ten hemi upper and lower sets of the fixed orthodontic appointment. Each set was composed of a rectangular wire SS (17 × 22 inches) with 2 bands and 10 SS brackets (0.018 inches), and 10 ligature wires (Dentarum, Germany). Each set was incubated in a 20 ml black glass container filled with 10 ml of deionized water for 12 hours. The glass container was covered with a well-fit plastic cover. All the containers were kept at 37 degrees Celsius in an incubator for 12 hours. The pH of the deionized water was measured before and after immersing the appliance. The number of ions released after 12 hours was measured by atomic absorption spectrophotometer.[28]

Statistical analysis

The statistical analysis was shown using IBM SPSS software version 28, and statistical significance was considered at $P < 0.05$. The sample size was determined using G Power software, with a power of 80%, $\alpha = 0.05$, and a constant proportion of 0.5. Descriptive data sets of means and standard deviations for each wire in the dry, deionized, and ionized conditions were compared using the Shapiro–Wilk test to assess normality. One-way ANOVA was used to compare the means of static force friction, and Duncan's test comparisons were used to evaluate group differences. Additionally, the *t*-test was used to assess the significance of the difference between the means of the two arch wires used. The level of significance was set at $P < 0.05$.

The Result

Static frictional force Results of stainless steel wire, stainless steel bracket with different media (Dry, deionized, and Ionized)

The outcomes of the Shapiro Wilk are shown in Table 1. Normality tests show that the data are normally distributed.

The descriptive statistics of Table 2 present the static friction of the SS arch wire alongside the outcomes of the ANOVA and the Duncan multiple range tests. Significant variances exist among the three groups (dry, deionized, and ionized water).

The mean static friction force of that ionized water group was a significant level lower than the mean static frictional force of the two other groups.

While the mean static friction force (deionized condition) followed closely after the iodized state. The dry condition has the highest mean force of static friction significance compared to the ionized and deionized conditions using SS (brackets, wire, and ligature wire).

Stainless Steel Brackets, Super elastic I archwire (Test wire) with different conditions (Dry, deionized, and Ionized water) at Static friction

The results of the Shapiro–Wilk test are shown in Table 3. Normality tests show that the data are normally distributed.

The descriptive data [Table 4] shows that the SS bracket (0.018 slots) and superelastic I archwire (Test wire) (0.018×.014 inches) in a dry condition at room temperature, had the highest mean force of static friction, followed by the same wire in a deionized state. In contrast, the static friction value of ionized water is the lowest. Table 4 shows the ANOVA, which displays a significant difference between the groups (dry, deionized, and ionized).

The comparison of static friction between Stainless steel wire (Control) and superelastic I arch (test wire) using Stainless steel bracket in three conditions (dry, Deionized, and ionized)

Table 5 presents the outcome of a *t*-test that compared the means of six different states for orthodontic wires in a static state. The wires tested included Static SS in three conditions (dry, deionized, and Ionized) states and Static I arch (test wires) in three conditions (dry, deionized, and Ionized). Each group had a sample size of 10, and the standard deviation, mean, and standard error mean were estimated for each group. The outcomes reveal a significantly different mean for the six groups, as indicated by the low P value (<.001) and high *t*-value of the *t*-test for the six groups at three conditions.

Table 1: The ShapiroWilk test of the static friction of SS archwire in three media

Condition	Shapiro–Wilk		
	Statistic	df	Sig
Dry	0.892	10	0.181
Deionized	0.901	10	0.223
Ionized	0.905	10	0.246

Table 2: Shows the descriptive statistics, ANOVA, and Duncan's tests of the mean of static frictional force for SSW in three conditions

Bracket/Wire	Condition	*n*	Mean	Duncan's Group**	Std. Deviation	Std. Error	*F*	*P**
SSB-SSW	Dry	10	175.76	C	0.617	0.195	121.95	<.001
	Deionized	10	170.23	B	0.342	0.108		
	Ionized	10	165.54	A	0.383	0.121		

*$P \leq 0.05$ represents the significant level differences between the three groups of the ANOVA analysis test; **different letters show a significant level difference among the groups; stainless steel wire=SSW. Stainless steel bracket=SSB

Table 3: The Shapiro–Wilk test of the static friction of I archwire in three media

Condition	Shapiro–Wilk		
	Statistic	Df	Sig
Dry	0.868	10	0.095
Deionized	0.946	10	0.624
Ionized	0.882	10	0.139

The results of the *t*-tests in Table 5 indicate significant-level differences between the mean values of the orthodontic wires tested. In the dry state condition, the mean value for the SS wire group was significantly level higher than the mean value for the I archwire (test wire) group. Similarly, in the static deionized wire condition, the mean value for the SS wire group was significantly higher than the mean value for the I archwire (test wire) group. The static-ionized SS wires also had a higher mean value than the static-ionized I archwires (test wire). These results highlight the importance of wire selection in achieving optimal treatment outcomes, as different wires can have significantly different frictional properties.

Result ionized water

After immersion in the appliance, the pH of the deionized water shows a reduction on the acidic side from (6.61) to (6.35), respectively, where PH_w = deionized condition (deionized water) and Ph_i = ionized condition (ionized water). Table 6 shows the ion release results after the appliance's immersion at 37 degrees for 12 hours, with Ni releasing the most among the samples, followed by Fe and other samples.

Result in AFM of wire (I archwire (Test wire) and SS) in three states (dry, deionized, and ionized)

This research utilized an AFM (Naio AFM Nanosurf, Switzerland) to analyze the surface topography of roughness of three distinct archwire types as Figure 1a-d and Figure 2e-h, The study examined three parameters' roughness, and a comprehensive comparison was performed across all three conditions for each archwire type. According to the descriptive statistics in Tables 7 and 8, the dry condition group exhibited the highest mean for all three parameters of roughness, followed by the deionized and ionized conditions in the two types of wire I archwire (Test wire) wire and SS archwires.

Results of the test roughness parameters (RQ, RA, and Mh) for three states (dry, deionized, and ionized) using stainless steel wire (SS)

Table 7 presents descriptive statistics for three different roughness parameters (RQ, RA, and Mh) for three states dry, deionized, and ion, along with the total score for 30 samples. The mean value for dry is higher than that for deionized and ionized. The standard deviations are relatively small, suggesting the data is clustered around the mean. The standard errors are also small, indicating a relatively high degree of precision in the mean estimates. Table 7 shows the outcomes of an ANOVA. It was accomplished that there was a significant difference among the means of the three groups, as evidenced by the very low *P* value (<0.001), which means that the results are statistically significant with a very high confidence level. And the large F-ratio [(258.644) for RQ and (202,61) for RA and (261,52) for Mh] suggests that the variance between these groups is much greater than the variance within groups. More specifically, the Duncan multiple range test, conducted after an ANOVA with three roughness parameters (RQ, RA, and Mh) for three conditions, showed that the mean static friction forces of the three conditions (dry, deionized, and ionized) are differences in significant levels, with dry being the highest and ionized being the lowest when using SS (brackets, wire, and ligature wire).

Results of the roughness parameters (RQ, RA, and Mh) for three states (dry, deionized, and ionized) using I archwire (Test wire) wire

The descriptive statistics Table 8 shown here summarizes the results of a study of parameters roughness (RQ, RA, and Mh) on I (Test Wire) material that looked at three different states: dry, deionized, and ionized. The I archwire (test wire) wire in the dry state of the mean value showed the highest statical frictional force, followed by deionized, while the Ion mean value exhibited the lowest. The largest standard deviation and the standard error suggest more variability in the ion data than in dry and.

Table 8 shows the ANOVA results which reveal that there were differences in significant levels between the three groups based on the resultant roughness parameters (RQ, RA, and Mh) in three states (dry, deionized, and ionized), as evidenced by the large

Table 4: Descriptive statistics, ANOVA, and Duncan's tests of the mean force of static friction for I archwire (a test wire) in three conditions

Bracket Wire	Condition	*n*	Mean	Duncan's Group	Std. Deviation	Std. Error	*F*	*P**
SSB- I archwire (Test wire) W	Dry	10	165.81	C	0.432	0.137	852.56	<.001
	Deionized	10	162	B	0.576	0.182		
	Ionized	10	157.63	A	0.389	0.123		

*$P \leq 0.05$ represent the significant-level changes between the three groups of the Anova test, **different letters represent a significant difference. SSB=Stainless steel bracket W=Wire

Table 5: Descriptive statistics and *t*-test to compare the mean static friction values for SS and I archwire (test wire) in three conditions

The condition	*n*	Mean	Std. Deviation	Std. Error Mean	*t*-test	
					t	Sig.
Dry SS wire	10	175.76	0.62	0.19	41.810	<.001
Dry I arch (test wire)	10	165.80	0.43	0.13		
deionized SS wire	10	170.23	0.34	0.10	38.9	<.001
deionized I arch (test wire)	10	161.99	0.57	0.18		
Ionized stainless steel	10	165.54	0.38	0.13	48.8	<.001
Ionized I arch (test wire)	10	157.10	0.37	0.12		

Table 6: Shows the main released metal ions from the fixed orthodontic appliance after a 12 h immersion appliance in deionized water at 37°

Ions released	Concentration (ppm)	Std. Deviation
Cu^+	0.19	0.0515
Ni^+	0.39	0.0425
Cd^+	0.12	0.0254
Mn^+	0.01	0.00311
Si^+	0.13	0.045
Cr^+	0.12	0.0125
Fe^+	0.23	0.0124

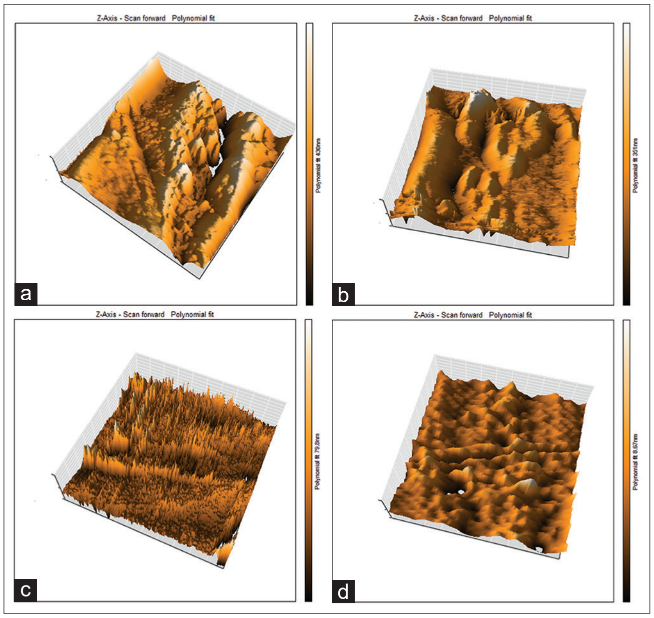

Figure 1: (a) stainless steel wire in standard condition (b) stainless steel wire in dry condition (c) stainless steel wire in deionized condition (d) stainless steel wire in ionized condition

F-values (484.57 for RQ), 158.15 for RA), and 661.38 for Mh, with a small significance level of "<.001." Presented Table 8 shows the results of a Duncan post-hoc test for the roughness parameters (RQ, RA, and Mh). After a significant ANOVA, the test was done to determine which of the three groups (ion, deionized, and dry) were most different. Where the ions were lowest, and the dry state was highest.

Discussion

In clinical orthodontics, the importance of friction has gotten a lot of attention, mostly because of the benefits that could come from reducing resistance to sliding. Lowering the resistance can reduce the time it takes to align the teeth and/or close the spaces between them, significantly impacting orthodontic treatment.[29] Static friction was reduction between the brackets and wire is essential to enable easy tooth movement.[30] The orthodontic appliance released metal ions from the first hour of bonding in the patient's saliva. This fully ionized media is incorporated between the brackets and arch wire during the sliding mechanics. The significant impact of this ionized media on static friction is unknown. This study aimed to search the effect of ions released from the fixed appliance on the static friction between the archwire and the brackets interface also to assess the static frictional resistance and surface topography of a novel material, NiTi superelastic (I archwire), and compare it to SS archwire. Stainless steel wire was employed in this study due to its superior characteristics, including the least frictional resistance, minimal surface roughness, lowest frictional coefficient, and sliding resistance compared to other materials, such as NiTi.[31,32] Researchers have always considered SS material the standard and reference to judge and compare the properties of new archwires (I archwire) in the field.[6] In previous studies that used a universal

Table 7: Descriptive statistics, ANOVA, and Duncan's multiple range test to compare the mean values of outcome variables among the three conditions (Dry and deionized states and ionized water) of materials for Roughness parameter (RQ, RA, and Mh) by (AFM) for SS wire

Roughness parameter	*n*	Mean	Std. Deviation	Std. Error	Duncan's Group	*F*	Sig
Dry RQ SS	10	55.87	0.41	0.13	C	258.6	<.001
Deionized RQ SS	10	52.64	0.22	0.07	B		
Ion RQ SS	10	51.70	0.57	0.18	A		
Dry RA SS	10	40.59	0.27	0.08	C	202.61	<.001
Deionized RA SS	10	38.09	0.08	0.02	B		
Ion RA SS	10	34.65	0.23	0.07	A		
Dry Mh SS	10	184.08	0.65	0.20	C	261.52	<.001
Deionized Mh SS	10	141.71	0.46	0.14	B		
Ion Mh SS	10	131.92	0.51	0.16	A		

Table 8: Descriptive statistics, ANOVA, and Duncan's multiple range test to compare the mean values of outcome variables among the three conditions (Dry and deionized and ionized water) of materials for Roughness parameter (RQ, RA, and Mh) by (AFM) for I archwire wire

Roughness parameter	*n*	Mean	Std. Deviation	Std. Error	Duncan's Group	*F*	Sig
Dry RQ I archwire (Test wire)	10	50.94	0.05	0.02	C	484.57	<.001
Deionized RQ I archwire (Test wire)	10	40.34	0.13	0.04	B		
Ion RQ I archwire (Test wire)	10	35.13	0.61	0.19	A		
Dry RA I archwire (Test wire)	10	39.02	0.49	0.15	C	158.15	<.001
Deionized RA I archwire (Test wire)	10	32.19	0.51	0.16	B		
Ion RA I archwire (Test wire)	10	27.20	0.39	0.12	A		
Dry Mh I archwire (Test wire)	10	169.4	0.44	0.2	C	661.38	<.001
Deionized Mh I archwire (Test wire)	10	156.34	0.5	0.14	B		
Ion Mh I archwire (Test wire)	10	103.6	0.3	0.1	A		

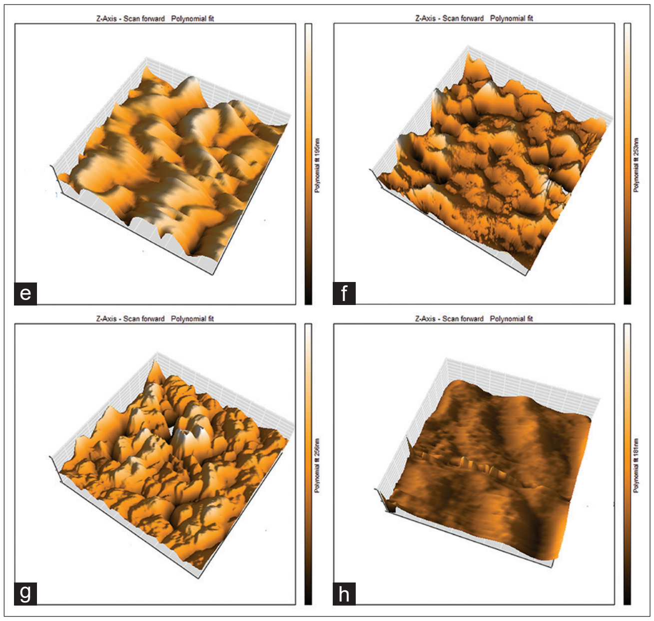

Figure 2: e (i archwire in standard condition), f (i archwire in dry condition), g (i archwire in Deionized condition), h (i arch wire in ionized condition

Instron machine, this machine was generally accepted as the standard and conventional method for testing the resistance to sliding.[17,27,33–36]

In this study, Roth prescription system was utilized as the bracket slid over the wire instead of pulling the wire through the bracket, as performed by another researcher. The selected method is a more realistic simulation of how teeth move in the mouth.[23,37] The first premolar was selected to perform this procedure as it slots torque is (-7) and has a zero tipping, which doesn't affect frictional resistance like the canine bracket. The torque up to 12 degrees significantly increased friction, although the increase was less than that observed for the tip alone.[38]

According to the current study, the newly designed NiTi wire has less friction than the standard SS wire in all situations. And this is clear when comparing two groups of wire types (*t*-test), SS and I-arch test wire, under various conditions. The results showed that dry I-arch test wire outperformed SS, which can be attributed to the more attractive design of the cross-sectional new wire. The reduction in the cross-section of the wire can effectively reduce friction, which explains the superior performance of I-arch test wire.[14,39]

In contrast to many previous studies that have suggested that the lowest frictional resistance is achieved with archwire alloys made of SS.[31,40-42]

This study found that ionized conditions led to less friction when using a SS wire than deionized conditions. This can be explained by the fact that the surface is full of ions, which reduces the number of surface irregularities (asperitus) and make the surface smoother. This smoothing effect, in turn, leads to a decrease in friction. and this is similar to I archwire (test wire). or The presence of such ionized polar liquids can increase adhesion and attraction due to heightened atomic attraction among ionic species[43–45] found that surface charge and roughness affect friction and adhesion between two surfaces in solution, with a non-charged surface providing the best adhesion and a charged surface providing poor adhesion. Increasing the roughness of the surface results in stronger adhesion, whereas decreasing the roughness leads to decreased friction.[46] Additionally, the friction decreased in the wet condition when using deionized water.[15] Add to that, the human saliva can reduce frictional force by 15–19%.[47] As a result, the results of the *t* test comparing ionized and deionized conditions using SS wire are explained.

According to the study, in wire tests (I archwire), I archwire's deionized state exhibited lower friction than the SS's deionized state. Similarly, the ionized condition of the I archwire demonstrated reduced friction compared to SS due to the exact underlying cause responsible for the decreased friction in a new wire.[14,15,39,43–47]

In contrast to some studies, it was found that the deionized state had the highest friction, which may result in larger bracket micro fractures. Additionally, brackets tend to increase surface roughness after clinical use, which can increase the coefficient of friction and friction force.[27,35,36,48]

Orthodontic wires play a vital role in orthodontic treatment, and the surface roughness of these wires can influence the frictional resistance between the bracket and wire. Several studies have utilized Atomic Force Microscopy (AFM) to evaluate the surface roughness parameters of orthodontic wires. By using AFM, precise surface roughness measurements can be obtained, leading to a better understanding of the impact of surface roughness on frictional resistance.[32,49]

The study was conducted to evaluate the surface roughness of several orthodontic arch wires using AFM. According to the study's findings, the SS archwire displayed reduced surface roughness compared to other archwires having the same wire cross-section. Surface roughness parameters such as Ra, Rq, and Mh are important tools for quantifying a surface's roughness degree.[50]

The present study found that the surface topography of the new I archwire was smoother compared to the SS wire. As RQ, RA, and Mh of I archwire (which measure roughness) value were significantly lower than SS archwire. Also, the roughness values increased more when the surface was dry than when it was deionized or ionized.

The roughness of the orthodontic wire is determined by the microscopic irregularities on the surface of the wire, known as asperities.[50] These asperities were found to be more pronounced in SS than in I archwire and also found to be less in deionized and ionized conditions. The effective area of contact between two surfaces is determined by these asperities that bear the entire load between the surfaces.

In general, an increase in surface roughness (Rq, Ra, and Mh) can lead to an increase in friction, especially in dry or boundary-lubricated conditions. This is because rougher surfaces have a higher contact area and produce more asperity (microscopic peaks and valleys) interactions, which can cause greater resistance to sliding.

Clinical application

The combination of I arch wire with a SS bracket and ligature wire can improve sliding mechanics, such as leveling, alignment, and space closure, due to its low-friction properties. As a result, the number of arch wires required per treatment can be reduced, as well as minimizes patient discomfort, reduces the chair time and treatment cost. The ions released from orthodontic appliances reduce the friction at the wire bracket interface that can highlight the advantage of these ions on the static friction but within the nontoxic level.

Limitation

The main limitation of the current study could be the use of new archwires regardless of the clinical situation, in which the retraction process of teeth takes several days. The other potential limitation of this study was using deionized water instead of saliva to test friction. Moreover, this laboratory investigation focused on comparing the friction generated by different combinations of brackets, ligatures, and archwires. It is crucial to note that, like any *in vitro* research, this study cannot replicate the clinical (*in vivo*) conditions encountered during orthodontic tooth movement. Furthermore, another limitation arises from the use of a universal Instron machine with a load simulation, as it fails to mimic the intricacies of actual tooth movement.

Conclusion

1. The highest average static friction force was observed when using a SS bracket and superelastic NiTi wire (0.018×0.014 inches) in dry conditions.
2. Deionized state had better static friction than the dry state for both I archwire and SS wire.
3. In the ion state, static friction was lower than deionized and dry states for both SS and new I

archwire, but new test wire performed the best in ion state.

4. New NiTi (I archwire) wire had lower static friction than old SS wire in all states.
5. AFM imaging showed that the roughness parameter was lower in ion and deionized states and highest in dry state for both conventional SS and new wire, but new wire had less roughness parameters than conventional SS wire.

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Ethical statement

According to college regulations, research materials that do not require ethics approval do not necessitate an ethical clearance for the study.

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Conflicts of interest

There are no conflicts of interest.

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