Tikrit Journal for Dental Sciences 12(2) (2024) 303-322
https://doi.org/10.25130/tjds.12.2.7

TjDs

Tikrit Journal
for
Dental Sciences
https://tjds.tu.edu.iq
ISSN:2073-1213

IRAQI
Academic Scientific Journals

Effect of Metal Ions Released from Fixed Orthodontic Appliance on Kinetic Friction of New I Archwire

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Keywords:
kinetic friction force; Sliding mechanics; archwire; Orthodontic brackets; Surface roughness parameters

Article Info.:

Article History:
Received: 25/8/2023
Received in revised form: 29/9/2023.
Accepted: 11/10/2023
Final Proofreading: 11/10/2023
Available Online: 1/12/2024

Citation: Yakop HS, Al Qassar SS, Aljoubory MA. Effect of Metal Ions Released from Fixed Orthodontic Appliance on Kinetic Friction of New I Archwire. Tikrit Journal for Dental Sciences 2024; 12(2): 303-322.
https://doi.org/10.25130/tjds.12.2.7

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Abstract

Background: kinetic friction force (KFF) between the orthodontic brackets and wire impacts to the sliding mechanics that affecting teeth movements and treatment duration. This sliding media is released metal ions from the fixed appliances. This study aimed to assess the KFF and surface topography of stainless steel and I archwires in dry conditions and in media fully with metal ions that released from fixed appliances.

Methods: In this research study, a set of 60 as-received straight archwires specimens (50 mm) length wire were employed and categorized into two groups based on the material type (30 super elastics new I archwires gauge (0.4572 x 0.3556 inch) and 30 stainless steel archwires 0.4572 x 0.5588" as a control (. The archwires' KFF was measured while sliding a loaded Roth Stainless Steel brackets (0.4572) on the archwire using a universal tensile testing machine in dry and metal ions released media. While the topography surface was assessed using a noncontact Atomic Force Microscope.

Results: KFF of I arch wire was significantly lower than SS wire in dry condition. Metal ions media released from fixed appliance significantly reduced KFF compared to dry condition for both wires. surface roughness reports revealed that the highest mean of all three roughness parameters was in SS group, followed by I arch wires in descending order. Additionally, Metal ions media significantly reduce all roughness parameters.

Conclusion: KFF of I archwire lesser than SS standard archwire in all conditions specially in ion media. Full ion media reduce KFF for both tested wires.

Introduction:

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. Therefore, the primary goal of orthodontic tooth movement is to decrease friction at the archwire-bracket interface (1,2). Friction refers to the counteracting force that arises between two objects in contact, hindering their relative motion and acting in the direction opposite to that of the surfaces in contact. In orthodontics, friction occurs when the bracket, arch wire, and ligature come into direct contact during the sliding mechanic's process (3). When attempting to move two surfaces that are not in motion, the minimum amount of force necessary to initiate tooth movement during orthodontic treatment is called static friction. On the other hand, once the surfaces are in motion, the force that opposes the direction of one object against another at a constant speed is known as kinetic friction. Understanding the difference between these two types of friction is essential for effective orthodontic treatment (4). The differentiation between static and kinetic friction is a critical factor in orthodontic tooth movement, as these two forms of friction produce distinct impacts on the process (5). Kinetic friction replaces static friction during the period of motion and is one of the factors that contribute to the entire resistance to sliding during tooth movement (4). It is, therefore, essential to comprehend the dissimilarities between static and kinetic friction to ensure successful orthodontic treatment.

Kinetic friction offers a valuable advantage in orthodontic treatments by allowing for precise regulation of tooth movement. The ability to adjust the frictional force can effectively slow down or even stop the speed of tooth movement, facilitating more controlled and accurate treatment outcomes. However, it is important to maintain a balance between friction and tooth movement to avoid potential adverse effects, such as prolonged treatment time, patient discomfort, and potential damage to the teeth. Therefore, optimizing frictional force is crucial to achieving successful orthodontic treatment outcomes (6).

In orthodontics, various methods can be employed to minimize kinetic friction during treatment. One such strategy is utilizing self-ligating brackets with an in-built mechanism to secure the wire, negating the need for metal or elastic ligatures. This design minimizes the interaction between the wire and bracket, resulting in reduced frictional forces (7). Additionally, low friction archwires are available to reduce the contact between the archwire and bracket, thus decreasing friction and allowing for more efficient tooth movement (6). The frictional forces between stainless-steel brackets and various wire materials were conducted using artificial saliva under both dry and wet conditions. The findings revealed that the incorporation of copper in the alloys led to an increase in friction for both conditions. Interestingly, the study also observed that the presence of artificial saliva exhibited a lubricating effect, resulting in reduced friction under wet conditions when compared to dry conditions (8).

Stainless steel was found to have the lowest frictional resistance among orthodontic wire alloys (9,10). Exposure to oral environment can increase corrosion and ion release (11). Additionally, the composition of the alloy used in the appliance can influence the amount of metal ions released, with nickel ions being released at higher levels than other metal ions from fixed orthodontic devices.

Additionally, the levels of chromium and nickel in the saliva were found to be highest during the first week following appliance placement, progressively diminishing over time (12). The I-arch system represents a groundbreaking and innovative approach to orthodontic archwire systems. This approach is characterized by its biological focus, high effectiveness, and ease of use. Rectangular archwires with immediate torque delivery are used at the alignment and levelling stage, resulting in exceptional effectiveness. Furthermore, the system is compatible with any straight-wire prescription. Gentle forces (starting at 23 g) ensure biological compatibility, reducing the traumatic effects and pain associated with orthodontic treatment, particularly at the beginning. This approach also reduces bone damage, primarily at the vestibular cortical level. Additionally, chair time and the number of archwires required for treatment are both reduced, as reported by (13).

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 kinetic 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.

Material and Method

Material Used for UTM (universal tensile machine)

This study utilized 60 straight archwire specimens, each 5 cm in length, divided into two groups based on material type:

Thirty superelastic new I archwires (0.4572 x 0.3556-inch SIA Orthodontic, Italy).

Thirty stainless steel archwires (0.4572 x 0.5588-inch SIA Orthodontic, Italy).

The archwires' kinetic friction was evaluated by sliding a SS Roth 0.4572 " (Dentaurum, Germany) bracket over them using a universal tensile machine (gester, China) with an oral texture simulation template. The stainless steel archwires are the control group, and the I archwires (test wire) are the test group. Tests wire was conducted on 60 Roth stainless steel brackets (Dentaurum, Germany) for the maxillary right bicuspid, which was ligated to the archeries with stainless steel ligature wires (Dentaurum, Germany). The tests were performed at zero tipping with (-7) torque (Frictional resistance doesn't affect the bracket. The torque up to 12 degrees significantly increased friction, although the increase was less than that observed for the tip alone (14). Meaning the torque does not affect to friction in experiment) and a new bracket, archwire segment, and ligature wire were used for each trial to prevent bias. The same examiner conducted all tests and procedures. The methodology utilized in this investigation draws upon established techniques for measuring friction (15). It involves the application of a singular, equivalent force to the root's resistance center to simulate the forces experienced by tooth roots (16). Before testing, all specimens were treated with an acetone solution to eliminate dust particles and residual oil layers from their surfaces.

Experimental setup for UTM (universal tensile machine)

The kinetic 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 stainless steel 0.4572-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 (17) at 8 mm spacing with a 16 mm space allotted for the movable bracket. The archwire samples were inserted into the slots (0.4572 ") 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 twisting's) using a Mathew needle holder (Dentarum, Germany) (15). In order to examine the effect of ionized and deionized water on frictional forces, ionized water was obtained from an orthodontic appliance submerged in deionized water. During frictional tests, the ionized water was administered to the bracket and archwire samples using a needle and syringe (18). A movable SS bracket with a 10 mm power arm was utilized to replicate the effect of a single equivalent force playing at the centre 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 (15). The bracket was moved at a rate of 5 mm/min across the central space for 50 mm, and load cell readings were obtained to determine the clinical force of retraction applied to the tooth (15).

The UTM software measured the 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(19). The kinetic frictional force was calculated by averaging data obtained for 3 seconds after the peak in the kinetic friction (20).

To test under ion and deionized media, ion and deionized water were continuously dropped onto the bracket and archwire sample using needle and syringe (18). 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 for both wires users (stainless steel and I archwire), were measured at a room temperature of 24C°. Each test (for each bracket-arch wire and ligature combination) was repeated ten times using a new as-received archwire, bracket, and ligature sample.

AFM (Atomic Force Microscope)

The surface topography of each archwire was examined using the AFM Nano surface microscope from Switzerland, which employed noncontact scanning techniques for assessing 3D surface configuration and roughness. To analyze samples of nearly straight specimens, three different preformed archwires were each sectioned into three 5 mm samples from the region where the bracket moves along the wire. These samples were then securely affixed to a metal holder using fast-drying cyanoacrylate glue and examined under ambient conditions via a Naio AFM (Nano surface microscope from Switzerland), operating in noncontact mode. Each specimen was analyzed by randomly assessing 60 areas (15 ×15 mm) on the surface, resulting in a total of 180 data points. The roughness parameters, such as RA (average roughness), RQ (Root mean square), and Mh (maximum value height), were measured by processing the three-dimensional images using Mountains 9 software. The analysis utilized specialized AFM probes with a curvature radius of less than 10 nm, mounted on cantilevers measuring 250 nm, with a spring constant of 0.1 N/m.

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

This experiment utilized ten hemi upper and lower sets of fixed orthodontic appointments, each containing a rectangular wire SS measuring 17 x 22 inches, two bands, ten stainless steel brackets (0.4572 inches), and ten ligature wires from Dentarum, Germany. To assess the release of ions, each set was immersed in a 20 ml black glass container filled with 10 ml of deionized water and then covered with a well-fit plastic cover. Following a 12-hour incubation period at 37 degrees Celsius in an incubator, the PH of the deionized water was measured before and after the immersion of the appliance. An atomic absorption spectrophotometer determined the number of ions released after 12 hours (21).

Statistical analysis

The statistical analysis was performed by 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. Normal distribution of the data was tested for each group comparison using the Kolmogorov-Smirnov test, and Levene's test was used for homogeneity of variance. Parametric tests were applied for all group comparisons, Descriptive data sets of means and standard deviations for each wire in the dry, deionized, and ionized. One-way ANOVA was used to compare the means of kinetic force friction, and Tukey 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 $p < 0.05$.

Result

The results in ionized water

Following immersion in the appliance, the deionized water's pH decreases toward the acidic end, changing from 6.61 to 6.35. PH_w and Ph_i represent the deionized condition (deionized water) and the ionized condition (ionized water). Table 1presents the outcomes of ion release after submerging the appliance at 37 degrees Celsius for 12 hours by using atomic absorption spectrophotometer. Among the samples, the highest release was observed for Ni, followed by Fe and other samples as in table 1.

Kinetic frictional force Results from Stainless-Steel wire, Stainless steel Brackets with different media (Dry, deionized, and ionized).

Table 1 shows the Shapiro-Wilk test and descriptive for stainless steel measuring kinetic frictional force in three conditions, from the table 2 show that the data are normally distributed. The data presented here is the result of an analysis comparing the performance of stainless steel (SS) wires under three different conditions: Dry SS wire (A), Deionized SS wire (B), and Ionized SS wire (C).

The statistical analysis uses one-way ANOVA and the Tukey Multiple Comparisons tests in Table 3 result show to evaluate the performance of stainless-steel wires under three conditions: Dry SS wire (A), Deionized SS wire (B), and Ionized SS wire (C). The Tukey Multiple Comparison tests show that all pairs of groups have significant mean differences, with p-values less than 0.001. This indicates that the performance of stainless-steel wires differs significantly under the three conditions: Dry, Deionized, and Ionized. Based on the mean differences, the Ionized SS wire (C) has the lowest mean value, suggesting it might perform best in the three conditions.

SS Bracket, Super elastic I archwire (Test wire) with different conditions (Dry, deionized, and Ionized water) at kinetic friction.

For all three conditions, the Shapiro-Wilk Statistic is above 0.8, which indicates that the data is approximately normally distributed in Table 4. The significance values for each condition are greater than 0.05, which means the null hypothesis (that the data is normally distributed) cannot be rejected. There are ten samples (N=10) for each condition.

The mean values for Dry I archwire, Deionized I archwire, and Ionized I archwire are 163.20, 158.83, and 155.36, respectively. The standard deviations are relatively small (0.62, 0.57, and 0.50, respectively), indicating that the data points are relatively close to the mean. The standard errors for each condition are 0.20, 0.18, and 0.16, respectively.

The one-way ANOVA in Table 5 reveals a significant difference among the three conditions with an F-value of 482.3 and a significance level (Sig.) of less than 0.001. This indicates a significant difference among the means of the three groups (Dry, Deionized, and Ionized). The Tukey multiple comparisons test was conducted to identify the specific differences between the groups.

Table 5 results show significant differences in the mean values between all the group pairs. In conclusion, these results indicate significant differences between the means of the three conditions (Dry, Deionized, and Ionized): Ionized was the lowest and dry was the highest.

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

Table 6 provided results from an analysis comparing the performance of two types of orthodontic wires: (I) archwires and stainless steel, under different conditions: dry, deionized water, and ionized water. Independent samples t-tests were conducted to determine if statistically significant differences existed between the mean values for each pair of groups.

Table 5 show T-test results for each pair of groups are as follows:

1. Dry Stainless Steel vs Dry I Archwire: t-value = 20.5, p-value (Sig.) < 0.001

2. Deionized Stainless Steel vs Deionized I Archwire: t-value = 28.5, p-value (Sig.) < 0.001

3. Ionized Stainless Steel vs Ionized I Archwire: t-value = 37.6, p-value (Sig.) < 0.001

In each comparison, the t-test results demonstrate a significant difference between the means of the stainless steel and I archwire groups under the corresponding conditions, indicated by p-values less than 0.001.

The statistical analysis indicates notable differences in the performance of stainless steel wires and I archwires under varying conditions, such as dry water, deionized water, and ionized water.

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

In this study, an AFM was employed to investigate the surface topography and roughness of three distinct archwire types, as depicted in Figure (1-a, b-2, c-3, d-4, e-5, f-6, g-7, h-8). The research focused on analyzing three roughness parameters and extensively comparing all three conditions for each archwire type. Based on the descriptive statistics in Tables 7 and 8, the dry condition group displayed the highest mean values for all three roughness parameters. This was followed by the deionized and ionized conditions for the wire I archwire (Test wire) and SS archwires.

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

Table 7 presents an analysis of the roughness parameters, including root mean square roughness (RQ), average roughness (RA), and maximum value height (Mh), for stainless steel under three different conditions: dry, deionized, and ion. Ten samples were examined for each condition, and the data is summarized in terms of mean, standard deviation, standard error, Duncan's groupings, F-ratios, and p-values (Sig). Statistical analysis reveals significant differences among the conditions for all roughness parameters, as evidenced by the F-ratios and p-values (Sig < .001). This finding indicates that environmental conditions considerably impact the surface roughness of stainless steel.

The dry condition consistently shows the highest mean values for all roughness parameters compared to the deionized and ion needs. This indicates that the surface is rougher under dry conditions. On the other hand, the ion condition demonstrates the lowest mean values, suggesting smoother surfaces under this condition. The deionized state falls in between the two extremes.

Duncan's groupings categorize the means into distinct groups for each roughness parameter. The dry condition is classified as Group C, the deionized condition as Group B, and the ion condition as Group A. The Duncan multiple range test, conducted after the ANOVA with the three roughness parameters (RQ, RA, and Mh) for the three conditions, demonstrated significant differences in the mean static friction forces of the dry, deionized, and ionized conditions. The dry condition exhibited the highest mean static friction force, while the ionized condition displayed the lowest when utilizing stainless steel (brackets, wire, and ligature wire).

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

The descriptive statistics table 8 below 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 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, friction management has gained substantial prominence, primarily due to the advantages of minimizing resistance to sliding. Decreasing this resistance can significantly expedite tooth alignment and/or gap closure, thereby improving orthodontic treatment outcomes (22). Reducing kinetic friction between brackets and wire is crucial to facilitating smooth tooth movement (23). The orthodontic appliance released metal ions from the first 2 hour of bonding in the patient's saliva (9). This ionized media is incorporated between the brackets and arch wire during the sliding mechanics. The significant impact of this ionized media on kinetic friction is unknown.

The objective of this research was to evaluate the impact of ion release from fixed appliances on the kinetic friction at the interface between archwire and brackets, and to assess the kinetic frictional resistance and surface topography of a newly industrialized material, NiTi super-elastic (I archwire), in comparison to stainless steel wire (SS archwire).

Historically, stainless steel (SS) material has been regarded as the benchmark for evaluating and comparing the properties of emerging archwires (I archwire) in the field(24,25). Previous research employing a universal Instron machine recognized this apparatus as the standard and conventional method for assessing resistance to sliding (26-30,41).

In the current research, the Roth prescription system was employed, wherein the bracket slides over the wire, as opposed to pulling the wire through the bracket, a technique used by another researcher. This chosen approach more accurately simulates the movement of teeth within the oral cavity (15,32). The first premolar was chosen for conducting this procedure due to its slot torque of -7 degrees and zero tipping, resulting in minimal impact on frictional resistance, unlike the canine bracket. A torque increases up to 12 degrees led to a significant elevation in friction, albeit less than the increase observed for the tip alone (14).

The findings of the current research demonstrated that the novel NiTi wire exhibited lower friction than the standard stainless-steel wire under all circumstances. This observation became evident when comparing the two wire groups (T-test), stainless steel (SS), and I-arch test wire, under various conditions. The outcomes indicated that the dry I-arch test wire surpassed the performance of SS, likely due to the enhanced design of the new wire's cross-sectional structure. A reduced cross-section in the wire can effectively decrease friction (33,34), thereby accounting for the superior performance of the I-arch test wire.

Numerous prior studies have suggested that archwire alloys composed of stainless steel (SS) are associated with the lowest levels of frictional resistance (10,22,35,36).

According to the current investigation, the utilization of ionized conditions resulted in lower friction while using a stainless-steel wire than deionized conditions. This phenomenon can be attributed to the abundance of ions present on the surface, which reduces the number of surface irregularities (asperities) and renders the surface smoother, the smoothing effect subsequently triggers a reduction in friction, a characteristic that is comparable to that observed in the I-arch test wire. Alternatively, the existence of ionized polar liquids may enhance adhesion and attraction owing to increased atomic interactions among the ionic species (8,37). 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 (38). Moreover, a reduction in friction was observed in wet conditions when utilizing deionized water (6). Furthermore, human saliva has been reported to decrease frictional force by approximately 15–19% (39). Consequently, the outcomes of the T-test, which compared ionized and deionized conditions using stainless steel wire, can be elucidated.

Based on the research, the deionized state of the I-arch test wire showed reduced friction compared to the stainless-steel wire in its deionized state. Likewise, the ionized condition of the I-arch test wire exhibited lower friction relative to the stainless steel wire, attributable to the same fundamental reason responsible for the diminished friction in the new wire (6,8,33,34,37-39). Contrary to certain research, this study discovered that the wet conditions exhibited the greatest friction, potentially leading to more extensive microfractures in brackets. Furthermore, brackets are likely to experience increased surface roughness after clinical usage, which may raise the coefficient of friction and the frictional force (29,30,40,42).

Orthodontic wires are essential components in orthodontic treatment, where their surface roughness significantly affects the frictional resistance between the bracket and wire. Numerous investigations have employed Atomic Force Microscopy (AFM) to assess the surface roughness parameters of orthodontic wires. Through the application of AFM, accurate surface roughness measurements can be acquired, enabling a more comprehensive comprehension of the influence of surface roughness on frictional resistance (42,31).

In the current research, the surface topography of the new I-arch test wire was observed to be smoother than that of the stainless steel wire. Notably, the RQ, RA, and Mh values, which are indicative of surface roughness, were considerably lower for the I-arch test wire than the stainless steel wire. Additionally, the roughness values exhibited a more significant increase in dry conditions compared to deionized or ionized states. The roughness of the orthodontic wire is determined by the microscopic irregularities on the surface of the wire, known as asperities (43). 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 stainless steel bracket and ligature wire has the potential to improve sliding mechanics, such as leveling, alignment, and space closure, due to its low-friction properties. Consequently, the number of archwires required per treatment may be reduced, leading to minimized patient discomfort, shortened chair time, and decreased treatment costs. Additionally, the ions released from the orthodontic appliance have been found to reduce friction at the wire-bracket interface, highlighting the advantages of these ions on kinetic friction while maintaining nontoxic levels.

Limitation

A primary limitation of the current study may stem from the employment of new archwires without accounting for the clinical context, wherein the retraction process of teeth often occurs over a period of several days. Another potential limitation of this study was the use of deionized water rather than saliva for testing friction. Additionally, the laboratory investigation was centered on comparing the friction generated by various combinations of brackets, ligatures, and archwires. It is imperative to acknowledge that, akin to any in vitro research, this study may not fully replicate the clinical (in vivo) conditions experienced during orthodontic tooth movement. Furthermore, an additional limitation stems from the employment of a universal Instron machine with load simulation, as it does not adequately replicate the complexities of actual tooth movement. This aspect should be taken into account when assessing the applicability of the study's findings to real-life tooth movement.

Conclusions

1.The greatest average static friction force was observed under dry conditions when utilizing a stainless steel bracket and super-elastic NiTi wire (0.4572 x 0.3556 inches).

2. In comparison to the dry state, the deionized and ionized states exhibited superior kinetic friction for both I archwire and SS wire.

3. In the ion state, kinetic friction was observed to be lower than in both deionized and dry states for stainless steel and new I archwire, with the new test wire demonstrating the best performance in the ion state.

4. The new NiTi (I archwire) wire displayed lower kinetic friction compared to the old stainless-steel wire across all states.

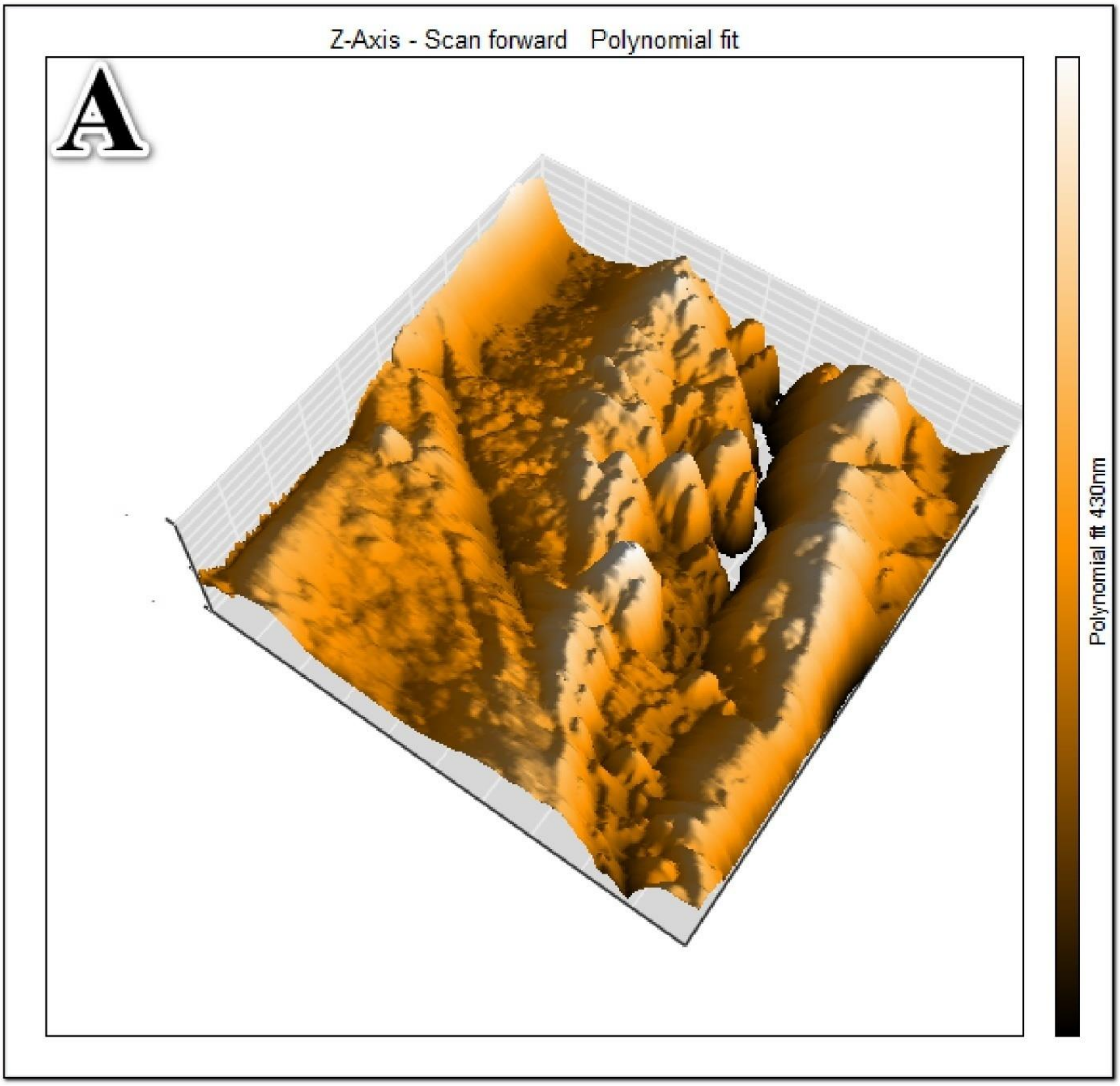

Figure 1-a-stainless steel wire in standard condition

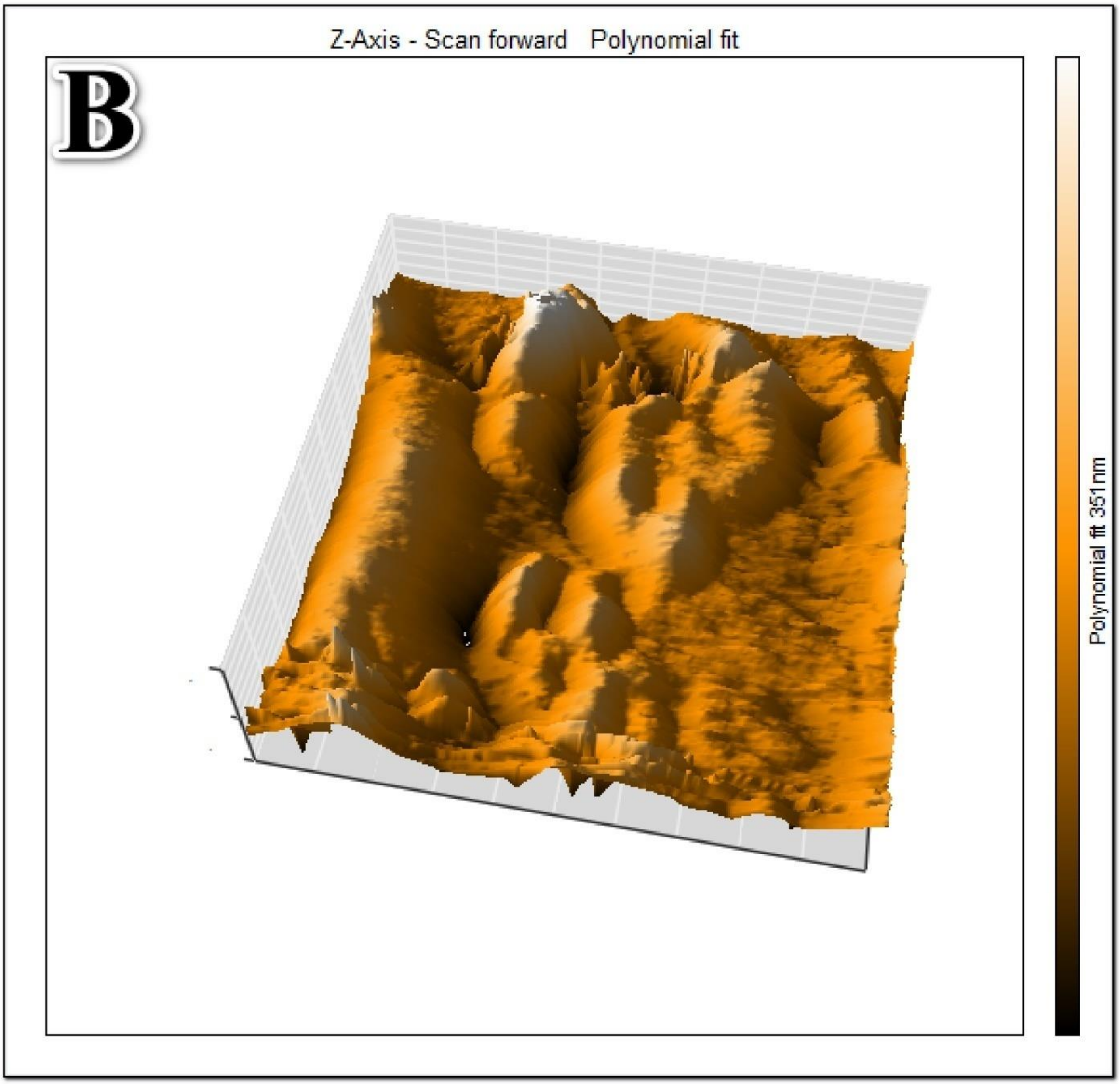

Figure 2-b -stainless steel wire in dry condition

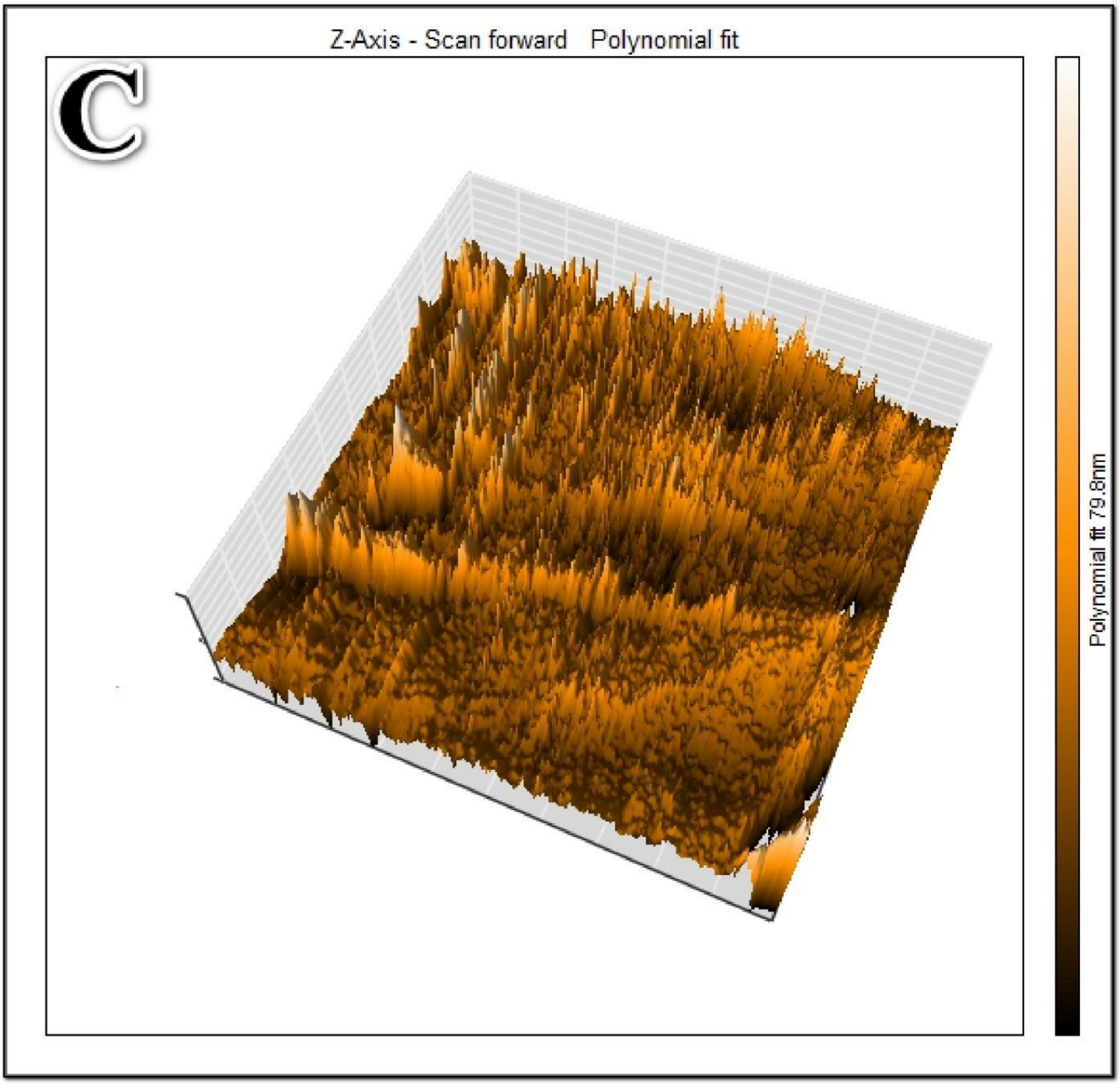

Figure 3-c - stainless steel wire in deionized condition

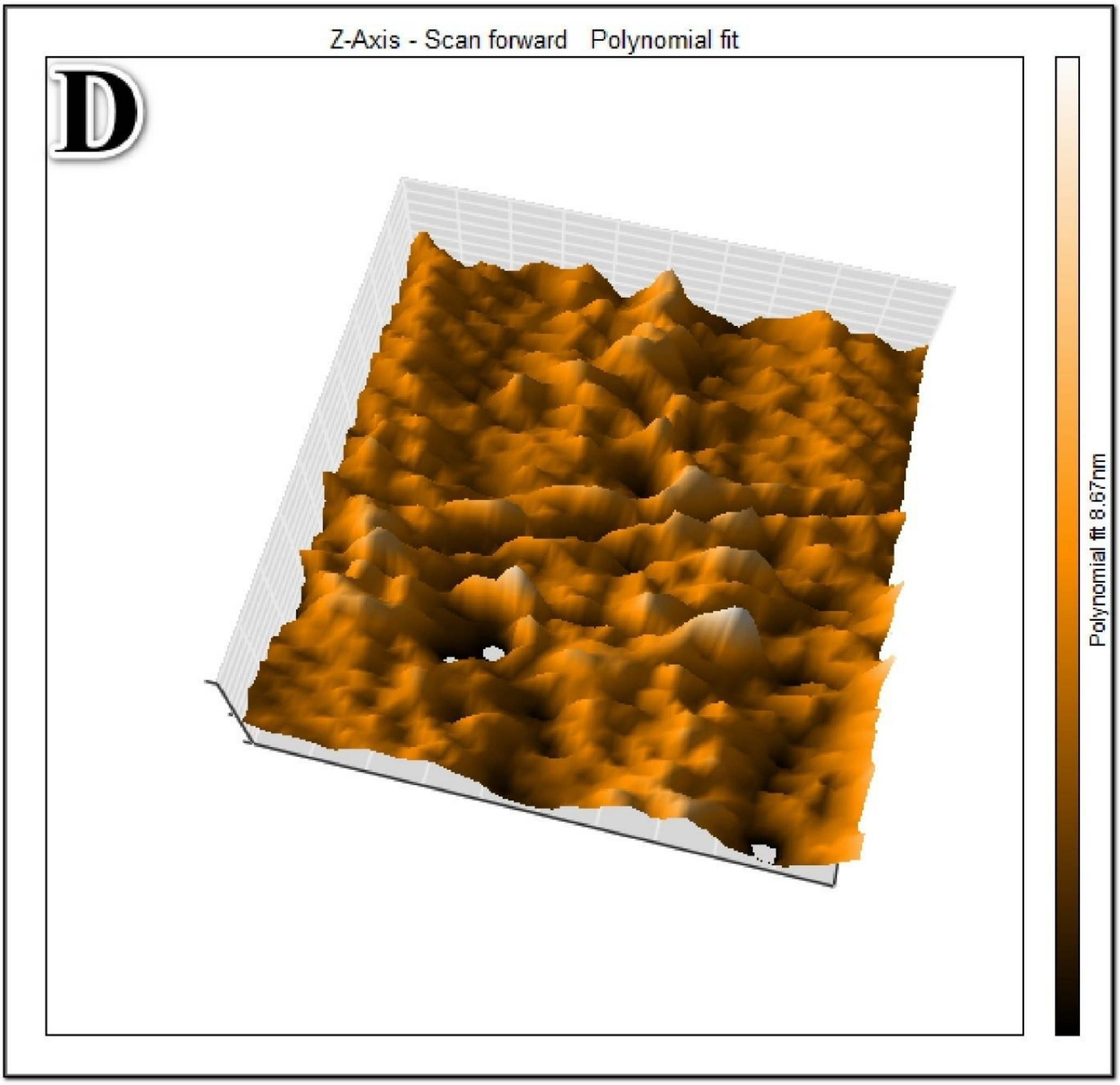

Figure 4-d - stainless steel wire in ionized condition

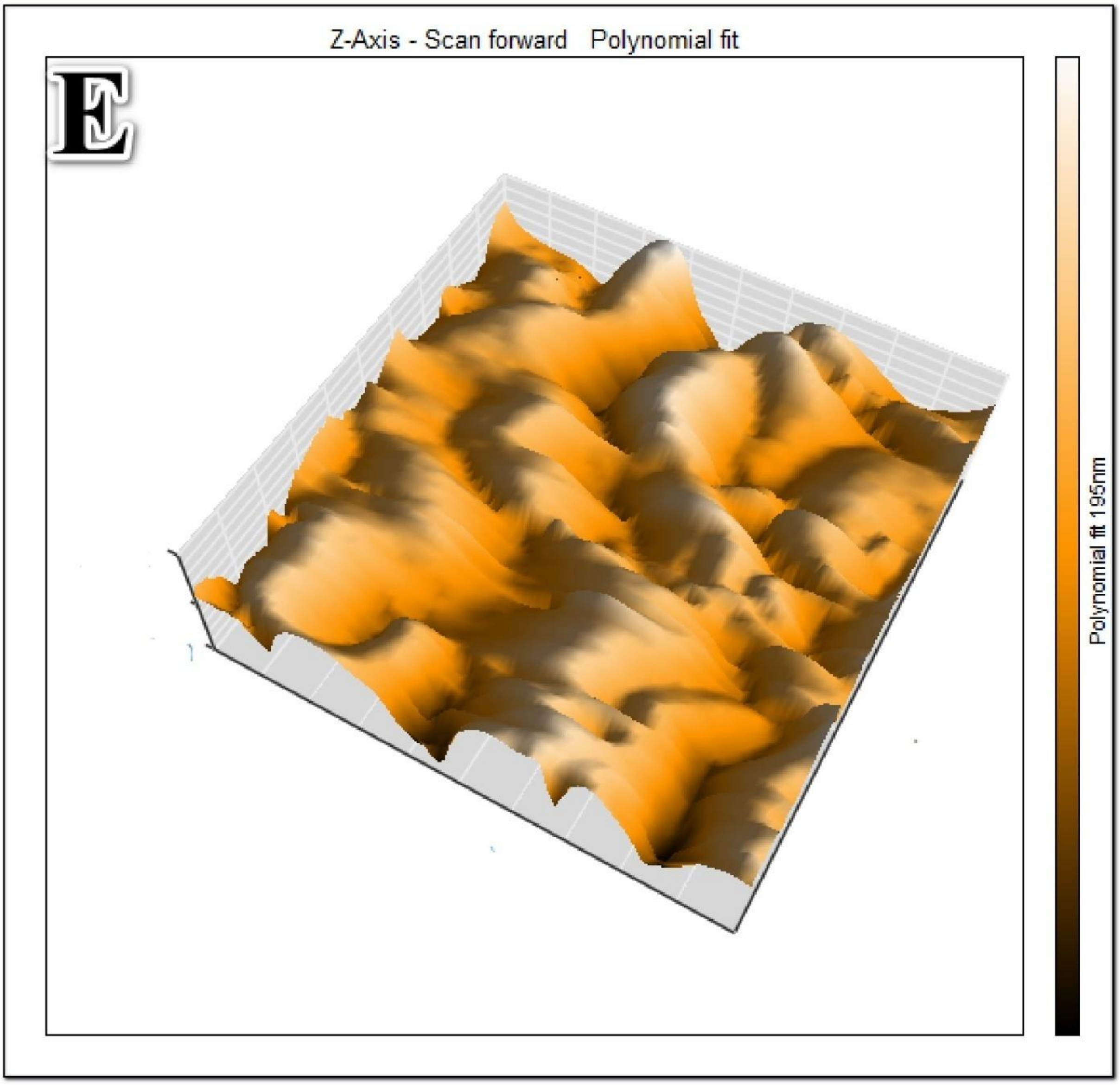

Figure 5-e -I archwire(Test wire) in standard condition

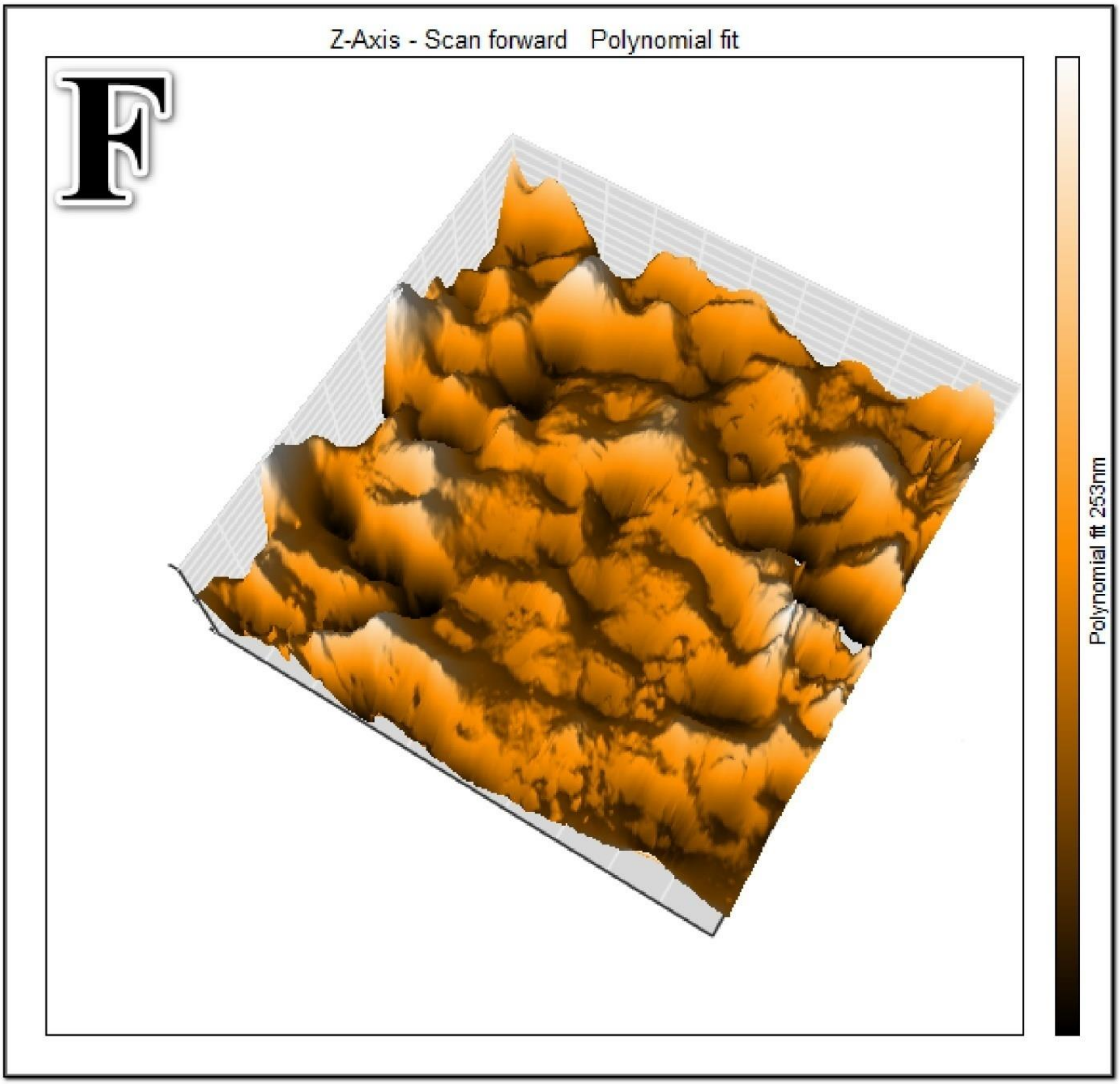

Figure 6-f - I archwire(Test wire) in dry condition

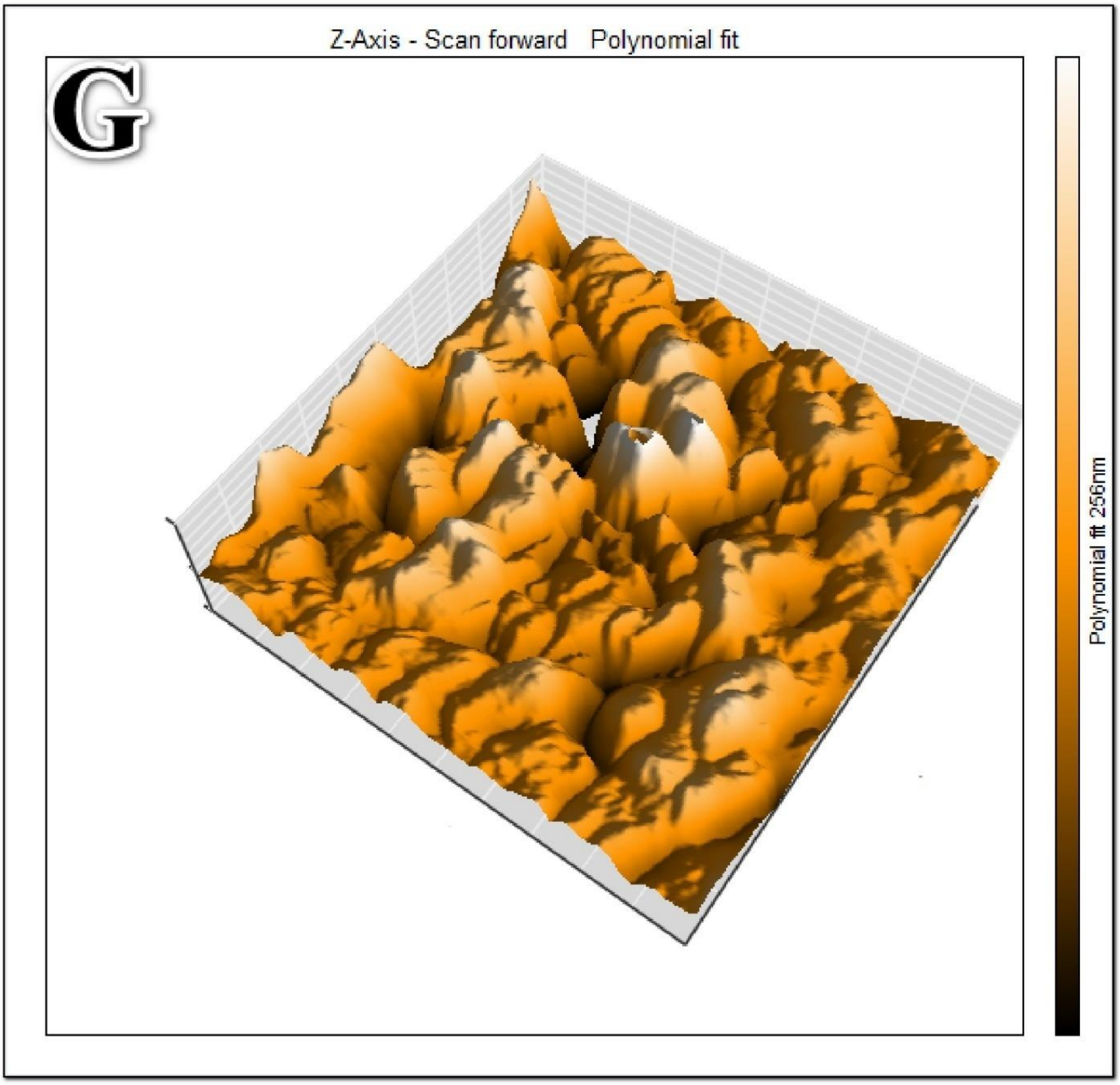

Figure 7-g - I archwire (Test wire) in deionized condition

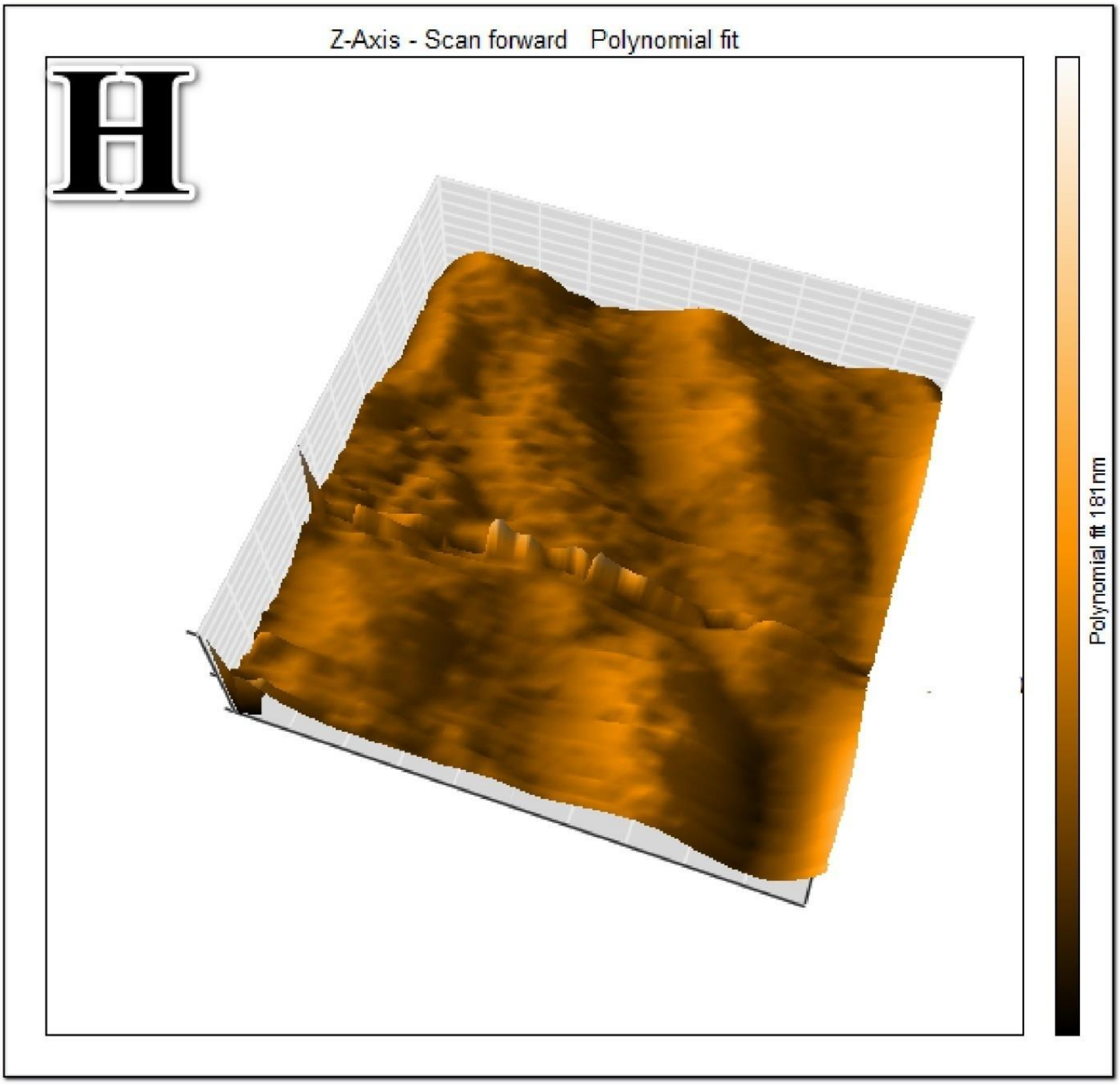

Figure 8-h - I archwire (Test wire) in ionized condition

Table 1 shows the main released metal ions from the fixed orthodontic appliance after a 12h immersion appliance in deionized water at 37°.

No.	Ions released	Concentration (ppm)	Std. Deviation
1	Cu^+	0.19	0.0515
2	Ni^+	0.39	0.0425
3	Cd^+	0.12	0.0254
4	Mn^+	0.01	0.00311
5	Si^+	0.13	0.045
6	Cr^+	0.12	0.0125
7	Fe^+	0.23	0.0124

Table 2 shows the Shapiro test and descriptive statistics of the mean of kinetic frictional force for SSW in three conditions.

	Shapiro-Wilk		Descriptive SS					
Conditions	Statistic	Sig.	N	Mean	Std. Deviation	Std. Error	Minimum	Maximum
Dry SS wire	0.880	0.130	10	168.9	0.63	0.2	168.02	169.84
Deionized SS wire	0.883	0.140	10	165.9	0.61	0.19	165.04	166.66
Ionized SS wire	0.962	0.810	10	164.1	0.47	0.15	163.78	164.98

Table 3 show ANOVA and Tukey Multiple comparisons for stainless steel measuring kinetic frictional resistance in three conditions

	ANOVA		Tukey Multiple Comparisons			
Conditions	F	Sig.	(I) Group	(J) Group	Mean Difference (I-J)	Sig.
Dry SS wire (A)	179.8	<.001	A	B	3.03*	<.001
Deionized SS wire (B)				C	4.84*	<.001
Ionized SS wire (C)			B	C	1.81*	<.001

Table 4 results show of the Shapiro-Wilk test and descriptive statistics for three different conditions (Dry , Deionized , and Ionized)

	Shapiro-Wilk		Descriptive SS					
Conditions	Statistic	Sig.	N	Mean	Std. Deviation	Std. Error	Minimum	Maximum
Dry I archwire	0.876	0.117	10	163.20	0.62	0.20	162.16	163.99
Deionized I archwire	0.910	0.278	10	158.83	0.57	0.18	158.12	159.87
Ionized I archwire	0.880	0.129	10	155.36	0.50	0.16	154.56	155.88

Table 5 shows the results of the one-way ANOVA and Tukey multiple comparisons for the three conditions

	ANOVA		Tukey Multiple Comparisons			
Conditions	F	Sig.	(I) Group	(J) Group	Mean Difference (I-J)	Sig.
Dry I archwire (A)	482.3	<.001	A	B	4.37*	<.001
Deionized I archwire (B)				C	7.83*	<.001
Ionized I archwire (C)			B	C	3.46*	<.001

Table 6 show Descriptive statistics and T-test to compare the mean Kinetic friction values for SS and I archwire (test wire) in three conditions.

Group Statistics						t-test	
Group condition		N	Mean	Std. Deviation	Std. Error Mean	T	Sig.
dry water	Dry Stainless Steel	10	168.94	0.63	0.20	20.5	<.001
	Dry I archwire	10	163.20	0.62	0.19		
Deionized water	Deionized Stainless Steel	10	165.97	0.56	0.17	28.5	<.001
	Deionized I archwire	10	158.83	0.57	0.18		
ionized water	ionized Stainless Steel	10	163.90	0.52	0.16	37.6	<.001
	ionized I archwire	10	155.36	0.50	0.15		

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 measured in µm) 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 measured in µm) 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		

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