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Research Article

Comparison of Surface Roughness of Conventional and Epoxy-coated Stainless Steel Arch Wires in Monocrystalline Ceramic Bracket and Stainless-Steel Bracket

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Abstract: This study aimed to compare the surface roughness between different combinations of epoxy-coated and stainless-steel arch wires in ceramic and stainless-steel brackets. **Materials and methods**: Two types of arch wires with a gauge of 0.019x0.025″ were used in this study: Fantasia non-coated stainless steel arch wire (SSA) (n=18) and tooth tone Epoxy-coated stainless steel arch wires (ECSSA) (n=18). The two types of arch wires were slid on two types of brackets of premolars of slot size 0.022x0.030″ roth prescription (n=36) divided equally into monocrystalline sapphire clear aesthetic ceramic brackets (CB) and Razor stainless steel bracket (SSB). The Ra surface roughness was measured using an atomic force microscope AFM to assess the wires before and after sliding them into ceramic and steel brackets. Six samples of wires received from the manufacturer were examined; additionally, six samples from each group of wires were taken after the friction test to examine the changes to the surface of the wires caused by the effect of the frictional force. For the statistical analysis, One-way ANOVA and Pairwise comparisons between groups, using the DUNCAN test at level of significance 0.05, by using SPSS software version 24. **Results**: ECSSA in CB had the highest value Ra (97± 60.1), followed by epoxy wire in steel brackets Ra (96.1 ± 52.9), followed by epoxy wire as received Ra (79 ± 60.1), followed by steel wire in ceramic bracket Ra (50.6 ± 24.3), followed by steel wire in steel bracket Ra (44.7 ± 23.4), the lowest values shown in steel wire as received Ra (28.2±13.3). One-way ANOVA showed a significant difference between the tested groups (P=value: 0.05). Duncan's test demonstrated significant differences among groups. **Conclusion**: Epoxy-coated SS arch wire combined with ceramic bracket shows the highest roughness properties, while SS arch wire combined with SS bracket and SS as received shows the lowest roughness properties.

Keywords: Ceramic brackets, Epoxy arch wires, Surface Roughness

INTRODUCTION

Surface roughness (SR) is a variation of the surface from the perfect form. It represents all the character's irregularities created during the manufacturing process and other factors that influence the surface texture [1]. The SR of arch wires controls the surface area in touch. Previous studies showed the SR effect on corrosion behavior, frictional characteristics, and biocompatibility; consequently, all these properties affect the clinical accomplishment of orthodontic arch wires. Plaque accumulation is also affected by SR, which is essential in other previously described properties. Various chemical, mechanical, and thermal stresses in the patient's mouth affect the orthodontic arch wire used in the treatment [2,3]. The stability of color, hygiene, and esthetics can be affected by the SR of orthodontic appliances, so SR represents essential factors during orthodontic treatment [4,5]. The SR is considered a necessary factor for the treatment quality because it affects the amount of generated friction, anchorage control, tooth movement speed, and bracket locking [6]. Other treatment-quality elements like metal ion release, biocompatibility, and corrosion behavior can also be affected [7,8]. Stainless steel (SS) alloy is one of the most significant popular alloys with encouraging properties and strength and is used to construct orthodontic brackets [9]. The metallic appearance of these brackets makes them less esthetic, but they have fantastic mechanical and functional properties [10]. The ceramic system, consisting of monocrystalline and polycrystalline, was introduced to the orthodontic field in 1980, It differs from plastic brackets, resists staining, and can withstand heavier forces without distortion [11]. Ceramic brackets have better dimensional stability, resist staining, better tolerate orthodontic forces, and can be custom-molded for individual teeth than plastic brackets [10]. So, these brackets have a mixture of the metal bracket's reliability and the esthetic appearance of plastic brackets [12]. SS arch wires have some properties, including tremendous flexibility, ease of welding, formability, ability to overcome sensitization and ability to undergo hard work without fracture. The advantages of SS are its biocompatible, excellent formability, low cost, and can be soldered and welded. Disadvantages of SS include high force delivery and relatively low spring back in bending compared to nickel-titanium and beta-titanium alloys. They can be susceptible to intergranular corrosion after heating to temperatures required for joining [13]. Metal alternatives that have been researched to create esthetic arch wires can make the orthodontic treatment done efficiently with the appliance visible labially [14]. Epoxy-coated wires are synthetic resin that consists of epoxide with another combination. It is applied by electrostatic technique to arch wires in which charged elements are used for coating electrostatically [15,16,17,18]. Epoxy cores have a high tensile SS and stable tooth-colored plastic coating [19]. The highest roughness value post-deflection is in epoxy-coated arch wires. The greater porosity occurs in the epoxy-coated arch wires, increasing SR [20]. The study hypothesis assumed no significant differences in SR among the different combinations of wires and brackets. This study aimed to compare the SR between different combinations of the epoxy-coated wire and SS brackets, epoxy-coated wire and ceramic brackets, SS wire and ceramic brackets, and finally, SS wire and SS brackets.

MATERIALS AND METHODS

Two types of orthodontic arch wires (Fantasia non-coated stainless steel arch wire (n=18) (International Orthodontic Service IOS™, Houston, USA) and tooth tone Epoxy-coated SS arch wires (n=18) (Ortho technology, West Columbia, USA) with a gauge of 0.019x0.025″ inch used in this study (figure 1). Two types of brackets of premolars of slot size 0.022x0.030″ Roth prescription, monocrystalline sapphire clear esthetic brackets (HUBIT et al. Gyeonggi-do, South Korea) (n=18) and Razor SS bracket (n=18) (International Orthodontic Service IOS™. California, USA) (figure 2). The SR was measured using an atomic force microscope AFM (NTEGRA prima NT-MDT, Moscow, Russia) (figure 3). The SR was estimated before and after sliding. The Ra parameter (Ra: is the average profile-to-mean line distance over assessment was used for examination SR [21]. Six wires as received were examined before and after sliding to examine the changes to the surface of the wires caused by the effect of the frictional force. To identify the exact area to be examined in the SR test, a mark was added to the wires with a permanent marker (only the wires that had been subjected to the friction test), the mark was made at the outer surface of the wire (the surface that did not touch the bracket slot) to indicate that only the surface of the wire opposite to the marked area required examination under the microscope seen (figure 4). In this way, the only part of the inner surface that had been slid along the bracket slot (which was 5mm) will be examined. While wires that did not go through the friction test (as received wires) did not require any marking, any area of the wire can be examined. The wires were then cut about 6 mm from both ends, resulting in a wire length of 20mm to ensure the wire's stability during the examination when passing the probe of AFM on the wire. The wires were secured to the metal slides with double-sided tape, with the marked area facing the slide and the opposing surface requiring examination facing the AFM probe. The AFM assessed SR (NTEGRA prima NT-MDT, Moscow, Russia) with a silicon probe mounted on a cantilever. It was used in tapping mode with a scan time of 540 seconds (9 minutes) at room temperature. Following the attachment of the wires to the metal slides, the slide containing the specimen was placed on the piezo scanner, and the microscope probe scanned the surface of the wire. The piezo scanner moved horizontally to provide the X and Y axes, while the probe moved vertically to provide the Z axis. The number of wires that had been examined were 36 wires (six SS wires as received, six SS wires after sliding in SS brackets, six SS wires after sliding in ceramic brackets, six epoxy wires as received, six epoxy wires after sliding in SS brackets and six epoxy wires after sliding in ceramic brackets), with a resolution of 256×256 pixels, the size of the scanned area was $30\times30 \mu m^2$ with a scan speed of 0.8line/s [22]. The area examined for the wires used in the friction test was the center of the 5mm that slides along the bracket slot, as opposed to the as-received wires, which can be examined in any area. Following that, a 3D view of the surface of the wire surfaces was displayed on the computer monitor connected to the AFM and was captured.

Figure (1): Arch wires for experimental study A: Tooth tone epoxy-coated stainless steel (Orthotechnology, West Columbia, USA). B: Fantasia non-coated stainless steel (International Orthodontic Service IOS™, Houston, USA).

Figure (2): A: Monocrystalline sapphire clear aesthetic brackets (HUBIT Co., Ltd. Gyeonggi-do, South Korea). B: Razor Stainless steel metal bracket (International Orthodontic Service IOS™. California, USA).

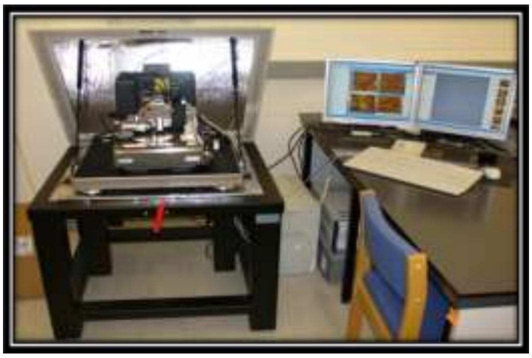

Figure (3): Atomic force microscopy (NTEGRA prima NT-MDT, Moscow, Russia)

Figure (4): The portion of the wire's outer surface that did not come into contact with the bracket slot is marked with a marker to indicate the area that slid along the slot.

Statistical analysis

The experiment's results were analyzed using SPSS (Statistical Package of Social Science, version 24, Inc. Chicago, USA). The Kolmogorov test was used to assess the normality distribution of the sample. The descriptive statistical analysis of the SR was calculated, including means, standard deviations, minimum, maximum, and range. One-way ANOVA multiple comparisons and Pairwise comparison Duncan's test was used to compare the mean of SR between different groups tested. The level of significance for all tests was determined at $P < 0.05$.

RESULTS

The results showed a normal data distribution, as the P-values > **0.05** of the Ra parameters (Table 1). The descriptive statistics of the roughness average (Ra) for each group are shown in Table 2. These values were expressed in nanometers (nm) for all of the samples that were evaluated. Epoxy wire in the ceramic bracket had the highest value, followed by epoxy wire in steel brackets, followed by epoxy wire as received, followed by steel wire in ceramic bracket, followed by steel wire in steel bracket, the lowest values shown in steel wire as received.

Using the ANOVA test, the SR measurements showed statistically significant differences in Ra parameters. Intergroup comparisons of the (Ra) parameter revealed that there were differences between groups as p-value 0.01 ($P < 0.05$) (Table 3). Duncan's test revealed that the groups of steel wire received no significantly lower value than steel wire steel bracket and steel wire ceramic bracket. However, they had a significantly lower value than other groups. Groups of epoxy wire steel brackets and ceramic brackets had no significant difference, but they had a significantly higher value than other groups. As received, groups of epoxy wire ceramic brackets had no significantly higher value than epoxy wire steel brackets, steel wire ceramic brackets, and epoxy wire. However, they had a significantly higher value than steel wire, steel bracket, and steel wire as received.

Table (1): Kolmogorov test for normality of data distribution of the (Ra) parameter

Groups	df	Sig.(Ra)
Epoxy wire- ceramic bracket	6	.200*
Epoxy wire- stainless steel bracket	6	.200*
Stainless steel wire-ceramic bracket	6	.200*
Stainless steel wire-stainless steel bracket	6	.200*
Epoxy wire as received	6	.200*
Stainless Steel wire as received	6	.200*

Table (2): Mean, standard deviation (SD), minimum, and maximum values of surface roughness (Ra) of the arch wires.

Groups	N	M±SD(Ra)	Minimum	Maximum
Epoxy wire- ceramic bracket	6	97.4 ± 19.6	71.50	122.00
Epoxy wire- stainless steel bracket	6	96.1 ± 52.9	41.80	191.80
Stainless steel wire-ceramic bracket	6	50.6 ± 24.3	20.90	94.50
Stainless steel wire-stainless steel br	6	44.7 ± 23.4	23.80	84.30
Epoxy wire as received	6	79.0 ± 60.1	26.80	189.90
Stainless Steel wire as received	6	28.2 ± 13.3	8.40	46.30

Table (3): A One-way ANOVA of surface roughness (Ra) of the arch wires and Pairwise comparisons between groups, using the DUNCAN test. (Ra) parameter

Groups	**Sum of Squares**	**df**	**Mean Sq**	**F**	**Sig.**
Between Groups	25122.185	5	5024.437	3.710	.010
Within Groups	40631.198	30	1354.373		
Total	65753.383	35			

Table (4): Duncan's test was used to compare the means of SR between the six groups tested.

Groups	N	1	2	3
steel-before	6	28.2000		
steel-steel	6	44.7500	44.7500	
steel-ceramic	6	50.6000	50.6000	50.6000
epoxy-before	6		79.0500	79.0500
epoxy-ceramic	6			96.1500
epoxy-steel	6			97.4667
Sig.		.329	.137	.051

DISCUSSION

The AFM was used in this investigation to analyze the topographic surface characteristics of orthodontic arch wires. This type of microscope obtains images using sensors comprising sharp points that interact with the surface of the specimen. The AFM is a member of the family of scanning probe microscopes, which is a class of instruments that gathers information on surfaces that have been detected utilizing interatomic interactions. This type of microscope obtains images by using sensors. The atomic force microscope (AFM) is a potentially useful tool for determining the surface qualities of dental materials, as stated by Kakaboura et al. (2007) and Lee et al. (2010) [23,24]. This device was selected for several reasons, including the fact that its scanning process is straightforward, that the specimen does not require any special preparation before it can be scanned, and that it quantitatively measures the surface's roughness in a three-dimensional configuration. As a result, there is no dependence on a subjective interpretation, in contrast to the scanning electron microscope (SEM), which relies on a personal interpretation of surface morphology images. This finding agreed with Winchester. 1991) concluded that the SEM was an unreliable approach for determining the roughness of the surface [25]. The Ra parameter indicates the absolute magnitude of the heights present on the surface (it represents the deviations of the height from the mean surface). According to this study's findings, the wires' sliding along the brackets caused more changes to the surface of the wires than before sliding. This change was demonstrated by the wires' parameter roughness (Ra) being more significant after the friction test than before the test, because most of the frictional force generated during interactions between the arch wire and the brackets is transmitted to the arch wire rather than the brackets, the surfaces of the wires experience an increase in roughness after the friction test. This is similar to the results of the study [22]. Groups of epoxy wire with steel brackets and epoxy wire with ceramic brackets had no significant difference, but they had a significantly higher value than other groups after being subjected to friction, in agreement with (6,20,26,27,28). The explanation is that epoxy wire has a higher porosity than uncoated arch wires, which increases the wire's roughness (29,20). The coating (kind of material) and method of application of this coating on the SS both play a role in determining the porosity of the coating. It is possible that the locations with a concentration of friction also function as porosity, which can cause coatings to crack when subjected to friction (30). In addition, the coating applied to orthodontic arch wires has the potential to affect the surface characteristics of those arch wires. As a result, the properties of coated arch wires, such as their thickness, SR, bacterial adhesion, mechanical properties, corrosiveness, scratch resistance, coating stability, and frictional properties, may be altered and degraded as they slide along the bracket slot (18,31). An increase in the thickness of the epoxy coating has the effect of modifying the mechanical properties, even though this improves the adhesion, dimensional stability, electrical insulation, and chemical resistance of the coating and the Interaction between the coating on the arch wire and the edges of the brackets (32,33). Our results disagree with (34) as they suppose that coatings applied to orthodontic wires serve as a lubricant and smooth out the surface irregularities, making it easier for the wire to slide over the brackets. In this study, the steel wires with steel brackets had a significantly lower roughness value after being subjected to friction. This agrees with (35,6). Both studies used AFM technology to compare roughness among groups; the result demonstrated that the steel wire had the lowest roughness value of the other groups. The explanation is that the steel wire had the smoothest surface. Because of its high hardness and strength, steel wire has been shown to have the lowest frictional coefficient and the lowest sliding resistance when used in a passive configuration (36). During orthodontic treatment, the quality of tooth movement is directly related to the roughness, which depends on the force exerted by two surfaces (37). In the clinical use of coated esthetic wires, it has been observed that the coating wears off over time (38).

CONCLUSIONS

Epoxy-coated SS arch wire combined with ceramic brackets shows the highest roughness properties, while SS arch wire combined with SS brackets shows the lowest. The present study verified the possibility of using SS wires combined with ceramic brackets, which presented satisfactory esthetics during the treatment and did not increase the SR, thereby not increasing the frictional resistance.

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Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript

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مقارنة خشونة السطح من أسلاك الفولاذ المقاوم للصدأ التقليدية والمغلفة بالإيبوكسي في قوس السيراميك أحادي البلورية وقوس الفولاذ المقاوم للصدأ

محمد اسماعيل, سعيد السماك

الملخص

الاهداف: تهدف هذه الدراسة إلى مقارنة خشونة السطح بين مجموعات مختلفة من الأسلاك المقوسة المطلية بالإيبوكسي والفولاذ المقاوم للصدأ في الحاصرات التقويمية السيراميك والفولاذ المقاوم للصدأ. **المواد وطرائق العمل**: نوعان من الأسلاك المقوسة بمقياس 0.019*0.025 انج استخدمت في هذه الدراسة. الاسلاك المقوسة المصنوعة من الفولاذ المقاوم للصدأ (عدد=18) والأسلاك المقوسة من الفولاذ المقاوم للصدأ مطلية بالإيبوكسي (عدد=18). تم انزلاق نوعي الأسلاك المقوسة على نوعين من الحاصرات التقويمية من الضواحك بحجم الفتحة 0.022*0.030 انج (عدد = 36) مقسمة بالتساوي إلى حاصرات تقويمية شفافة جمالية من السيراميك وحاصرات تقويمية غير قابلة للصدأ من الفولاذ. تم قياس خشونة سطح Ra باستخدام مجهر القوة الذرية AFM لتقييم الأسلاك قبل وبعد انزلاقها في الحاصرات التقويمية من السيراميك والفولاذ. تم فحص ست عينات من الأسلاك الواردة من الشركة المصنعة بالإضافة إلى ستة عينات من كل منها تم أخذ مجموعة من الأسلاك بعد اختبار الاحتكاك لفحص التغيرات التي طرأت على سطح الأسلاك الناتجة عن تأثير قوة الاحتكاك. **النتائج**: الحاصرات التقويمية السيراميك مع الاسلاك المقوسة المصنوعة من الفولاذ المقاوم للصدأ المطلية بالايبوكسي كانت أعلى قيمة (97± 60.1)، يليها الحاصرات التقويمية المصنوعة من الفولاذ المقاوم للصدأ مع الاسلاك المقوسة المصنوعة من الفولاذ المقاوم للصدأ المطلية بالايبوكسي (96.1± 52.9), يليها الاسلاك المقوسة المصنوعة من الفولاذ المقاوم للصدأ المطلية بالايبوكسي غير مستعمل (79± 60.1)، يليها الحاصرات التقويمية الخزفية مع الأسلاك المقوسة المصنوعة من الفولاذ المقاوم للصدأ(50.6± 24.3)، يليها الحاصرات التقويمية المصنوعة من الفولاذ المقاوم للصدأ مع الأسلاك المقوسة المصنوعة من الفولاذ المقاوم للصدأ(44.7± 23.4)، أدنى القيم الموضحة كانت في الأسلاك المقوسة المصنوعة من الفولاذ المقاوم للصدأ كما تم استلامها من المصنع(28.2± 13.3). أظهر ANOVA أحادي الاتجاه فرقًا كبيرًا بين المجموعات المختبرة. أظهر اختبار Tukey Post HOC اختلافات كبيرة في قوة الاحتكاك بين المجاميع, وتم استخدام اختبار Duncun للمقارنة الزوجية لمقارنة متوسط خشونة السطح بين المجموعات المختلفة التي تم اختبارها. **الاستنتاجات**: تظهر الأسلاك المقوسة من الفولاذ المقاوم للصدأ مطلية بالإيبوكسي مع الحاصرات التقويمية الشفافة من الياقوت الأحادي أعلى خصائص خشونة ، بينما تظهر الأسلاك المقوسة المصنوعة من الفولاذ المقاوم للصدأ مع الحاصرات التقويمية غير قابلة للصدأ من الفولاذ والأسلاك المقوسة المصنوعة من الفولاذ المقاوم للصدأ كما تم استلامها من المصنع أقل خصائص خشونة.