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FARKLI TİPTEKİ KAPAKLI LİNGUAL ORTODONTİ BRAKETLERİ İLE ARK TELLERİ ARASINDAKİ SÜRTÜNME DİRENCİNİN *in vitro* OLARAK DEĞERLENDİRİLMESİ

In vitro EVALUATION OF FRICTIONAL RESISTANCE BETWEEN DIFFERENT SELF LIGATING LINGUAL BRACKETS AND ARCHWIRES

Gülşilay Sayar [1], Yıldız Öztürk Ortan [2], Bülent Aydemir [3]

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Özet

Sürtünme, ortodontide mekanoterapiye direnç gösteren ve etkin diş hareketini sağlamak için dikkatle değerlendirilmesi gereken bir olgudur. Bu çalışmanın amacı, üç farklı tipteki kapaklı lingual ortodonti braketleri ile eşlenen nikel titanyum ve paslanmaz çelik tellerin 0°, 5° ve 10° açılanmalarda oluşturduğu statik ve kinetik sürtünme dirençlerini değerlendirmektir. Bu çalışmanın sıfır hipotezi ortodontik ark telleri ile eşlenen üç farklı tipteki kapaklı ortodonti braketlerinin sürtünme direnç değerleri arasında anlamlı bir farklılık olmadığıdır.

Evolution™, In-Ovation® L ve Phantom ™ sağ üst kanin braketleri (0,018x0,025 inç slot) ile 0,016 inç nikel titanyum, 0,016 inç paslanmaz çelik ve 0,016x0,022 inç boyutlu paslanmaz çelik ark telleri arasındaki sürtünme dirençleri kuru ortamda test edildi. Sürtünme dirençleri evrensel test cihazı ile değerlendirildi. Ayrıca braketlerin slot genişliği ölçüldü. Braket slotlarının yüzey pürüzlülüğü atomik kuvvet mikroskobu ve taramalı elektron mikroskobu ile incelendi. Tüm açılanmalardaki tüm kombinasyonlarda en düşük statik sürtünme direnci In-Ovation® L ile 0,016 inç nikel titanyum (2,00±0,02 N) ark teli arasında 0° açılanmada ve en yüksek direnç ise Evolution™ braketler ile 0,016x0,022 inç paslanmaz çelik teller arasında oluşmuştur (5,53±0,55 N). Tüm açılanmalarda statik sürtünme dirençleri kinetik sürtünme dirençlerinden daha yüksek bulundu. Phantom ™ braketlerim en büyük slot genişliğine sahip olduğu belirlendi ve In-Ovation® L ve Evolution ™ braketlerin Phantom ™ braketlerinden daha az slot genişliğine sahip olduğu bulundu. Braketler arasında slot yüzey pürüzlülüğü açısından anlamlı farlılık bulunmadı. Çalışmanın sıfır hipotezi reddedildi.

Anahtar kelimeler: Sürtünme, Ortodonti, Kapaklı braket.

Abstract

Friction is a phenomenon in orthodontics that resists the mechanotherapy and should be evaluated carefully for achieving efficient tooth movement. The aim of this study was to evaluate the static and kinetic frictional resistance (FR) resulting from the combination of three different types of self ligating lingual brackets and nickel titanium and stainless steel archwires at 0°, 5° ve 10° angulations. The null hypothesis of this study was that there was no significant difference between friction values of three different lingual brackets combined with the orthodontic archwires. Frictional resistances between Evolution™, In-Ovation® L, Phantom™ right upper canine brackets (0.018x0.025 inch slot) and 0.016 inch nickel titanium (NiTi), 0.016 inch stainless steel (SS) , 0.016x0.022 inch dimension of stainless steel (SS) archwires were tested in dry states. Frictional resistances were evaluated with the universal testing machine. Slot width of the brackets were also measured. Surface roughness of the brackets were investigated with atomic force microscopy and scanning electron microscopy. In all combinations at all angulations the lowest static frictional resistance occured between In-Ovation® L and 0.016 inch NiTi (2.00±0.02 N) at 0° and the highest occured Evolution™ brackets between 0.016x0.022 inch SS (5.53±0.55 N). At all angulations, static frictional resistance values were greater than kinetic frictional resistance values. Phantom™ brackets were determined having the greatest slot width and respectively In-Ovation® L and Evolution™ brackets have lesser slot widths than Phantom™ brackets. There were no statistically significant diferrences in surface roughness between all of the brackets. The null hypothesis was rejected.

Key words: Friction, Orthodontics, Self ligating bracket.

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[1] Dr. Öğretim Üyesi, İstanbul Medipol Üniversitesi Diş Hekimliği Fakültesi Ortodonti anabilim Dalı, İstanbul, Türkiye. ORCID ID: 0000-0003-3294-2644, silaysayar@yahoo.com, [2] Profesör Dr., Serbest Ortodontist, [3] Dr. Mühendis, Ulusal Metroloji Enstitüsü, TÜBİTAK, Gebze, Kocaeli, Türkiye, ORCID ID: 0000-0001-6848-2681

1. INTRODUCTION

In fixed orthodontic treatment, when an archwire is ligated into brackets, frictional resistance (FR) begins and continues during tooth movement. FR causes the loosing of an applied force and changing efficiency of tooth movement. (Nanda & Ghosh, 1997) Tooth movement will occur only when the applied forces adequately overcome the friction at the bracket-wire interface. (Kapila, Angolkar, Duncanson, & Nanda, 1990, pp. 117-126) Therefore, orthodontists should assess quantitative frictional forces to predict the effects of mechanics and obtain an optimal biologic response for efficient tooth movement. (Angolkar, Kapila, Duncanson, & Nanda, 1990, pp. 499-506)

In orthodontic sliding mechanics, friction is affected by physical-mechanical factors, such as archwire properties, archwire ligation, and bracket characteristics, or by biological factors, such as saliva, dental plaque, acquired pellicle, corrosion, and food particles (Nanda&Ghosh, 1997; Kapila, Angolkar, Duncanson, & Nanda,1990, pp. 117-126; Angolkar, Kapila, Duncanson, & Nanda,1990, ss. 499-506; Rossouw, 2003, pp. 64-72)

Self-ligating brackets were first described in 1935 by Stolzenberg by the name “Russell Lock” edgewise attachment. (Harradine, 2008, pp. 5-18) This type of bracket design has been advocated to assist with the reduction of friction and to provide secure archwire ligation, certain full-bracket engagement of the archwire, good oral hygiene, less chairside time, and patient comfort.

Lingual brackets are bonded to the lingual surfaces of the teeth and have a wider variety of characteristics than labial brackets. These brackets were first introduced in 1968 by Kinya Fujita who used the first lingual appliance system in 1975. (Fujita, 1979, pp. 657-675) Lingual brackets are invisible and provide the best fixed orthodontic treatment for adults. However, they produce some technical difficulties compared with the labial orthodontic system. (Kanj, Bouserhal, Osman, & El Sayed, 2018, pp. 39) Lingual brackets typically have a smaller profile and dimensions than labial brackets. The thickness of the brackets may cause irritation of the tongue. Moreover, bracket placement is affected by the different anatomical lingual surface of the teeth, and the lingual arch perimeter is shorter than the labial one. The ligation of the brackets may be difficult because of the lingual gingival margins. Therefore, lingual bracket designs have been developed to overcome these problems.

The idea of using self-ligating brackets in lingual orthodontics was first introduced by Neumann and Holtgrave, who bonded labial self-ligating brackets on the lingual surface of the teeth. (Geron, 2008, pp. 64-72) Many lingual bracket designs were produced over the years after the first self-ligating lingual brackets (Phillipe 2D), but only a few designs became popular. Treatment efficiency has improved through the use of self-ligating brackets in lingual orthodontics. (Harradine, 2008, pp. 5-18; Geron, 2008, pp. 64-72)

Nevertheless, there is limited knowledge of self-ligating lingual brackets in literature. The aim of this study was to evaluate the static and kinetic frictional resistance resulting from the combination of three different self-ligating lingual brackets and archwires. The null hypothesis of this study was that there was no statistically significant difference between the friction values of the three different lingual brackets combined with orthodontic archwires.

2. MATERIALS and METHODS

Three types of right upper canine lingual self ligating brackets (N=90) were tested in the study were as follows: Phantom™ polycarbonate brackets with passive clip mechanism (n=30) (Gestenco International, Gothenburg, Sweden), Evolution™ metallic brackets with active clip mechanism (n=30) (Adenta GmbH, Gliching, Germany), and In-Ovation L® metallic brackets with interactive clip mechanism (n=30) (GAC International, Bohemia, NY). The sample size was calculated with a 95% confidence interval (CI) and α of 0.05, and 90 brackets (n = 30 brackets of each group) were found sufficient to have the power 80%.

All brackets had 0.018 inch slot size and were tested with three types of orthodontic archwires belong same manufacturer: 0.016 inch nickel titanium (NiTi), 0.016 inch stainless steel (SS), 0.016x0,022 inch stainless steel (SS) (G&H, Greenwood, U.S. & Canada). A total of 270 bracket- archwire couples were studied and each couple was tested twice to eliminate the influence of wear and to secure test reliability. The method of our study was planned similar to the research of Redlich et al. (Redlich, Mayer, Harari, & Lewinstein, 2003, pp.. 69-73), to achieve 0° angulation and torque values, the brackets were bonded on 90x 40x1 millimeter (mm) size of aluminate plates using 0.018x0.025 inch stainless steel wire jig. The brackets were bonded on plates with Transbond™ XT (3M Unitek, Monrovia, Calif) primer and Transbond™ XT (3M Unitek, Monrovia, Calif) adhesive paste. The frictional testing apparatus was mounted on the upper fixed component of the mechanical testing machine. After placing the archwires and closing the caps of the brackets, the frictional resistances were evaluated with the universal testing machine (Zwick model Z250, Zwick/ Roel Ulm, Germany). (Figure1) This machine has upper and lower vertical components that parallel to each other and the upper one is fixed. The lower part has the ability to move with a definite speed and frictional forces are transmitted to a computer hard disk. Testing machine was calibrated from 0 to 10 Newton (N) for the study before each series of test. Each archwire was 25 cm length, the free end of the test wires were restrained with weighing 200 g and the wire was pulled 2 mm along the bracket slot for two minutes at a rate of 1mm/min. (Figure 2) Frictional resistance (FR) was recorded by using the software program of testing machine. The archwire-bracket couples were tested at θ values of 0°, 5° and 10, all testing was done in the dry state and at room temperature of 21°±2°C.

Evaluation of Bracket Slots

Slot roughness of the brackets was evaluated by scanning electron microscopy (SEM) (Philips XL 30 S) at 250X (Figure 3) and the surface morphology of them was assessed by using atomic force microscopy (AFM) at 50X magnification. (Figure 4) Before SEM and AFM evaluations, each bracket was cleaned with 95 per cent ethanol and rinsed with air. To investigate 3D slot roughness of the slots, 10 samples of each type of brackets and a total of 30 brackets were used for AFM (Nano scope IV Scanning Probe Microscope Controller, Veeco Instruments Inc., Plainview, New York, USA) assessment. AFM scanning size was 10X10 micrometer (μm). Bracket slot sizes were measured by using the optics of Galvision micro hardness tester (Galileo, Italy). The occluso-gingival distance of eight samples of each bracket type measured for twice in mil value (1 mil=0.001 inches), a total of 48 measurements were done.

Statistical Analysis

All statistical analyses were performed with a statistical software (IBM SPSS Statistics 21.0; IBM, Armonk, NY, USA). Descriptive statistics including the mean, standard deviations (SD), median and minimum-maximum values were calculated for each bracket and archwire combination. The significant differences between the groups were tested by using Kruskal Wallis test. Mann Whitney U test was used to define the group differences. Friedman and Wilcoxon signed-rank tests were used to investigate the differences between 0^0, 5^0 and 10^0 angulations. The level of significance was set at $p<0.05$.

3. RESULTS

Effect of Angulation

Among all the archwire-bracket combinations at all angulations, the lowest static frictional resistance occured between In-Ovation® L and 0.016 inch NiTi (2.00±0.02 N) at 0° and the highest occured Evolution™ brackets between 0.016x0.022 inch SS (5.53±0.55 N) at 10°. In all combinations frictional resistance showed an increase with increasing of the angulation. Statistical significant differences were found between frictional resistance of different brackets coupled with different archwires at 0°, 5°, 10° angulations ($p<0.001$). (Table 1)

Effect of Archwire Size

Mann Whitney U Test results showed that 0.016 inch NiTi archwires showed significantly lower FR than that of 0.016 SS and 0.016x0.022 inch SS (p:0.001; $p<0.01$). But there was no statistically significant difference between static FR of 0.016x0.022 inch SS and 0.016 inch SS ($p>0.05$).

Effect of Bracket Types

There was statistically significant difference between static FR of Evolution™, In-Ovation® L and Phantom™ brackets ($p<0.01$). At all combinations Evolution™ brackets showed significantly higher FR values than In-Ovation® L and Phantom™ brackets (p:0.001; $p<0.01$).

The results of kinetic frictional resistance presented same charactheristics with the static frictional resistance. (Table 2) Static and kinetic frictional resistance of different bracket types were shown in Table 3 and Table 4.

AFM Results

The slot surfaces of Phantom™ brackets were more rough (Ra: 24.99±18.71), whereas Evolution™ (20.189±20.22) and In-Ovation® L (Ra: 13.00±11.50) brackets had less surface roughness. Results of the statistical tests revealed that there were no statistically significant differences between surface roughness of the three types of brackets which observed with AFM analysis.

SEM Results

The SEM observations of the bracket slots were shown in Figure 3. The slot surface of Evolution™ brackets were more porous and rougher than that of the other brackets. Smoother slot surfaces were present in Phantom™ and In-Ovation® L brackets.

Slot Width Results

Slot size findings showed that all of the brackets had different size from the manufacturer's prescription. In-Ovation® L and Phantom™ brackets were wider and Evolution™ brackets were narrower than manufacturers' label values. (Table 6)

4. DISCUSSION

Orthodontic tooth movement is possible when the applied force can overcome friction and stimulate a biologic tissue response in the periodontium. For efficient mechanotherapy, the clinician should assess the frictional force values of fixed orthodontic appliances. (Rossouw, 2003, pp. 64-72; Mendes & Rossouw, 2003, pp.236-250)

When the bracket slides along the archwire, a resistance to sliding occurs at the archwire-bracket interface. Up to 60 percent of an applied force can be lost due to friction. Increasing the FR causes a decrease in treatment efficiency, as well as an increase in chairside time and the treatment period. Labial and lingual self-ligating brackets have been produced to eliminate the FR of elastomeric or wire ligatures.

In this study we aimed to compare the frictional resistance of lingual self-ligating brackets with different archwires. However, our study had four limitations; 1-in vitro nature of the study was a major limitation, in vivo studies would provide more precise knowledge about this issue, 2-the absence of saliva. Saliva and dental plaque may affect the FR values, 3-furthermore, in this study, the archwire movements were conducted at different angulations but in the same direction. In the oral cavity, the archwire can move in the three dimensions of the space, according to the tooth malposition, 4- the absence of control group, if a control group were added that contained conventional brackets, this study would be more valuable.

The results of our study showed that in all combinations, increasing the archwire size resulted in an increase in the FR. These findings confirm those of previous studies. (Angolkar, Kapila, Duncanson, & Nanda, 1990, pp. 499-506; Berger, 1990, pp. 219-228; Tanne, Matsubara, Shibaguchi, & Sakuda, 1991, pp. 285-290) The engagement of the archwire was more accurate in oversized wires, which we believe was the main factor contributing to the increased friction.

At 0^o angulation, ligation force was the main component of classical friction, and the friction was not related to the archwire size. It is well known that in the presence of second-order angulation, archwire size is the main factor affecting FR. (Kusy & Whitley, 1989, pp.235-240; Tidy & Orth, 1989, pp. 249-254; Smith & Rossouw, 2003, pp. 262-280; Tecco, Caputi, Traini, Di lorio, & D'Attilio, 2005, pp. 1041-11045)

According to the literature, we expected a difference between the rounded and the rectangular SS archwires at 10^o angulation. In consistency with this opinion, Evolution™ and In-Ovation® L brackets coupled with 0.016 inch SS and 0.016x0.022 inch SS showed significantly different FR values. However, in the Phantom™ brackets, no differences were found. When there is a gap between the archwire and bracket slot, the situation is passive configuration, and the contact angle between the archwire and bracket slot is lower than $3\text{-}7^o$. In some situations, when the contact angle between the archwire and bracket slot is more than $3\text{-}7^o$, the sliding stops, and a binding occurs between the archwire bracket couple. In our opinion, the angle between the

0.016 inch SS archwire and Phantom™ brackets was greater than the critical contact angle and causing binding to occur. Due to the binding, a mechanical abrasion (notching) formed at this angulation, and round wires showed higher FR values. This finding is consistent with Frank and Nikolai (1980, pp. 593-609), who reported that at binding angulations, a point contact occurs between brackets and round wires causing forces to distribute across a smaller surface, which results in an increase of FR. Evolution™ brackets showed the highest FR in all combinations examined in this study. At all angulations, the 0.016 inch SS showed significantly higher FR than the 0.016 inch NiTi when combined with Evolution™ brackets. In our opinion, the active clip mechanism of the Evolution™ brackets induced more friction on the SS wires than on the NiTi wires. The Evolution™ brackets showed the same results at 5° and 10° angulations, and these findings confirm previous studies. (Frank& Nikolai, 1980, pp. 593-609; DeFranco, Spiller, & von Fraunhofer, 1995, pp. 63-72; Peterson, Spencer, & Andreasen, 1982, pp. 563-571, Ho&West, 1991, pp. 95-99; Dickson & Jones, 1996, 516-518; Pereira, Gimenez, Prieto, Prieto, & Basting, 2016, pp.34-40)

At 5° and 10° angulations, Phantom™ brackets tested with 0.016 inch SS wires created significantly higher FR than the 0.016 inch NiTi. At 5° angulation, there was no significant difference between the FR values of the 0.016 inch NiTi and 0.016 inch SS coupled with In-Ovation® L brackets. We think that the bracket material type and the passive ligation mechanism of the bracket were the main factors contributing to this finding. When angulation reached 10°, In-Ovation® L brackets tested with 0.016 inch SS wires created significantly higher FR than 0.016 inch NiTi. Frank and Nikolai have noted that at high angulations, bending stiffness is a dominant factor on FR, and NiTi archwires have low friction values because of their lower stiffness. Our finding agrees with the findings of Frank and Nikolai (1980, pp. 593-609), Articolo and Kusy. (1999, pp. 39-51)

In our study, with an increase in second-order angulation and/or archwire size, FR increased much more in In-Ovation® L than Phantom™ brackets. In our opinion, this finding relates to the interactive clip mechanism of the In-Ovation® L brackets and/or their different design. As a result, at 5° angulation, significant differences were found in 0.016x0.022 inch SS wires between 0.016 inch SS. At 10° angulation, Evolution™ brackets created the highest FR with 0.016x0.022 inch SS wires, and the lowest FR was on Phantom™ brackets. In-Ovation® L brackets showed an increase in FR and presented similar results to Evolution™ brackets. Our opinion is that the interactive clip mechanism of the In-Ovation® L bracket might apply pressure on the rectangular wire, resulting in increased FR. (Lalithapriya, Kumaran,& Rajasigamani, 2015, pp.19)

At 0° angulation, Evolution™ brackets created the highest friction with 0.016 inch NiTi wires, followed by Phantom™ and In-Ovation® L brackets respectively. At 5° and 10° angulation, the highest FR values were shown by Evolution™ brackets, and lowest by Phantom™. At second-order angulation, the interactive clip mechanism may cause an increase of FR in In-Ovation® L brackets. At 10° angulation, the FR values of Evolution™ brackets were highest and significantly different from In-Ovation® L and Phantom™ brackets. Phantom™ brackets created the lowest FR, and, in our view, the polycarbonate material of the Phantom™ brackets may cause mechanical abrasion followed by notching on the 0.016 inch NiTi, as well as increased FR. The kinetic FR values of the archwire-bracket couples showed similar results to the static FR values. These findings confirm previous studies. (Clocheret, Willems, Carels, & Celis, 2004, pp. 63-170; Cacciafesta, Sfondrini, Ricciardi, Scribante, Klersy, & Auricchio, 2003, pp. 395-402; Burstone, 1981, pp. 1-16; Baccetti, Franchi, & Camporesi. 2008, pp. 120-124; Downing, McCabe, & Gordon, 1994, pp., 349-357; Moore, Harrington, & Rock, 2004, pp. 579-583; Taylor & Ison, 1996, pp. 215-222) All the brackets had different slot sizes, prescribed by the manufacturers. Phantom™ brackets were the widest, followed by In-Ovation® L and Evolution ™ brackets respectively.

The measurement of surface roughness can be performed by SEM or AFM analyses. SEM analysis is admitted to be insufficient for quantitative analysis and the real-time changes of the used samples. AFM analysis provides a three-dimensional assessment and quantitative evaluation of the samples. (Choi, Kim, Kim, Lee, Kim, Kim, & Park, 2016, pp. 1193-1199) In this study, we preferred to use both these analyses and compare the results. According to the SEM results Evolution™ brackets had the roughest surface and In-Ovation® L the smoothest. The FR results of the Evolution™ brackets showed positive correlation with the results of the SEM analysis. The lowest mean surface roughness (R_a) value was shown by the In-Ovation® L brackets and the highest by the Phantom™ brackets. However, a statistical evaluation of the AFM investigation showed that there was no difference between the surface roughness of the brackets. The difference in the SEM and AFM results confirmed that a quantitative assessment is needed to evaluate surface roughness. The mean values of surface roughness (R_a) presented no positive correlation between the FR test results. The Evolution™ brackets showed higher FR than the other brackets, in spite of having no difference in slot roughness values according to the AFM analysis. Surface roughness was not found to directly affect the FR, and this result confirms previous reports. We think that after the beginning of sliding, the frictional forces of the surfaces change because of mechanical abrasion. Hence, the actual coefficients of friction are independent of the initial roughness of the surfaces. Therefore adhesion friction may occur with even smoothest surfaces. (Kusy& Whitley JQ, 1990, pp. 300-312, Kusy & Whitley, 1999, pp.199-208; Ozturk Ortan& Yurdakuloglu Arslan, 2011, pp. 119-125)

5. CONCLUSIONS

Our study demonstrated that;

1-Bracket type, archwire size, and angulation between the archwire and the bracket slot significantly affect the FR. Therefore, the null hypothesis of this study was rejected.

2-Evolution™ brackets created the highest FR values at at 0°, 5°, and 10° angulations and in all combinations, which may result from the active clip mechanism and the bracket's respectively narrower slot than the others used in this study.

3-The clip mechanism of the self-ligating brackets have changing effects on the archwire, and active clips may increase the friction more than passive ones when coupled with rectangular wires.

Table-1. Results of static frictional resistance according to arch wires. bracket types and angulations.

Bracket Type	**Archwire Size**	**n**	**0^0 Angulation**	**5^0 Angulation**	**10^0 Angulation**	***p***	***P***		
			Mean±SD (Median)	**Mean±SD (Median)**	**Mean±SD (Median)**		**0º -5º Angulation**	**0º -10º Angulation**	**5º -10º Angulation**
Evolution	**0.016 SS**	10	3.36±0.13 (3.31)	3.68±0.27 (3.70)	3.91±0.16 (3.93)	***0.001*****	0.028*	0.005**	0.013*
	0.016x0.022SS	10	3.60±0.58 (3.79)	4.68±0.35 (4.74)	5.13±0.42 (5.25)	***0.001*****	0.005**	0.005**	NS
	0.016 NiTi	10	2.32±0.03 (2.32)	2.56±0.11 (2.57)	2.98±0.11 (2.93)	***0.001*****	0.005**	0.005**	0.005**
In-Ovation L	**0.016 SS**	10	2.00±0.01 (1.99)	2.19±0.15 (2.18)	2.80±0.25 (2.76)	***0.001*****	0.007**	0.005**	0.005**
	0.016x0.022SS	10	2.01±0.01 (2.01)	3.69±0.17 (3.76)	5.28±0.30 (5.33)	***0.001*****	0.005**	0.005**	0.005**
	0.016 NiTi	10	1.99±0.02 (1.98)	2.21±0.02 (2.20)	2.49±0.03 (2.49)	***0.001*****	0.005**	0.005**	0.005**
Phantom	**0.016 SS**	10	2.07±0.06 (2.05)	2.33±0.14 (2.33)	3.31±0.27 (3.22)	***0.001*****	0.005**	0.005**	0.005**
	0.016x0.022SS	10	2.24±0.44 (2.04)	2.99±0.73 (2.7)	4.08±1.35 (3.17)	***0.001*****	0.005**	0.005**	0.005**
	0.016 NiTi	10	2.05±0.04 (2.04)	2.13±0.03 (2.13)	2.48±0.22 (2.43)	***0.001*****	0.005**	0.005**	0.005**

Friedman test.

NS, not significant, *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

Table-2. Results of kinetic frictional resistance according to arch wires. bracket types and angulations.

Bracket Type	**Archwire Size**	n	**0^0 Angulation**	**5^0 Angulation**	**10^0 Angulation**	***p***		***p***	
			Mean±SD (N) (Median)	**Mean±SD (N) (Median)**	**Mean±SD (N) (Median)**		**0º -5º Angulation**	**0º -10º Angulation**	**5º -10º Angulation**
Evolution	**0.016 SS**	10	3.60±0.23 (3.52)	4.05±0.46 (3.98)	4.18±0.28 (4.24)	***0.020****	*0.047**	*0.017**	*NS*
	0.016x0.022SS	10	3.79±0.64 (4.00)	5.02±0.45 (4.97)	5.53±0.55 (5.54)	***0.001*****	*0.005***	*0.005***	*NS*
	0.016 NiTi	10	2.38±0.05 (2.37)	2.65±0.14 (2.68)	3.15±0.16 (3.12)	***0.001*****	*0.005***	*0.005***	*0.005***
In-Ovation L	**0.016 SS**	10	2.02±0.02 (2.01)	2.22±0.16 (2.21)	2.86±0.27 (2.82)	***0.001*****	*0.007***	*0.005***	*0.005***
	0.016x0.022SS	10	2.03±0.03 (2.02)	3.83±0.22 (3.91)	5.51±0.28 (5.53)	***0.001*****	*0.005***	*0.005***	*0.005***
	0.016 NiTi	10	2.00±0.02 (2.00)	2.25±0.03 (2.23)	2.58±0.05 (2.58)	***0.001*****	*0.005***	*0.005***	*0.005***
Phantom	**0.016 SS**	10	2.08±0.06 (2.06)	2.35±0.15 (2.35)	3.42±0.27 (3.29)	***0.001*****	*0.005***	*0.005***	*0.005***
	0.016x0.022SS	10	2.27±0.45 (2.07)	3.08±0.77 (2.86)	4.38±1.64 (3.29)	***0.001*****	*0.005***	*0.005***	*0.005***
	0.016 NiTi	10	2.05±0.02 (2.05)	2.15±0.03 (2.14)	2.53±0.23 (2.44)	***0.001*****	*0.005***	*0.005***	*0.005***

Friedman test.

NS, not significant, *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

Table-3. Static frictional resistance stratified by different bracket types.

(Mann Whitney U test results.)

Archwire Size	**Bracket Type**	**0^0 Angulation**	**5^0 Angulation**	**10^0 Angulation**
		***P* value**	***P* value**	***P* value**
0.016 SS	Evolution/InOvationL	0.001**	0.001**	0.001**
	Evolution/ Phantom	0.001**	0.001**	0.001**
	In-OvationL/Phantom	0.001**	0.050*	0.001**
0.016x0.022SS	Evolution/InOvationL	0.001**	0.001**	NS
	Evolution/ Phantom	0.001**	0.001**	0.041*
	In-OvationL/Phantom	0.004**	0.007**	0.023*

0.016 NiTi	Evolution/InOvationL	0.001**	0.001**	0.001**
	Evolution/ Phantom	0.001**	0.001**	0.001**
	In-OvationL/Phantom	0.001**	0.001**	NS

Table-4. Kinetic frictional resistance stratified by different bracket types.

(Mann Whitney U test results.)

Archwire Size	Bracket Type	0^0 Angulation	5^0 Angulation	10^0 Angulation
		***P* value**	***P* value**	***P* value**
0.016 SS	Evolution/InOvationL	0.001**	0.001**	0.001**
	Evolution/ Phantom	0.001**	0.001**	0.001**
	In-OvationL/Phantom	0.001**	0.050*	0.001**
0.016x0.022SS	Evolution/InOvationL	0.001**	0.001**	NS
	Evolution/ Phantom	0.001**	0.001**	0.049*
	In-OvationL/Phantom	0.004**	0.007**	0.041*

0.016 NiTi	Evolution/InOvationL	***0.001*****	***0.001*****	***0.001*****
	Evolution/ Phantom	***0.001*****	***0.001*****	***0.001*****
	In-OvationL/Phantom	***0.001*****	***0.001*****	NS

Table-5. Mean values of surface roughness's (R_a nanometer (nm)).

Bracket Type	**n**	**Ra**
		Mean±SD (nm) **(Median)**
Evolution	**10**	20.189±20.22 (10.88)
In-OvationL	**10**	13.00±11.50 (9.04)
Phantom	**10**	24.99±18.71 (19.56)
p		***0.205***

Table -6. Mean values of slot widths in mil.

Bracket Type	n	Minimum Bracket Slot Width	Maximum Bracket Slot Width	Bracket Slot Width X±SS (mil)	Deviation from manufacturers' value (mil)
Evolution	**8**	16.72	18.48	17.36±0.63	0.67±0.63
In-OvationL	**8**	17.88	18.55	18.25±0.24	0.25±0.24
Phantom	**8**	18.03	19.81	18.89±0.55	0.89±0.55

Figure 1. Test machine.

Figure 2. Angulation of the test device.

Figure 3. SEM views of the brackets.

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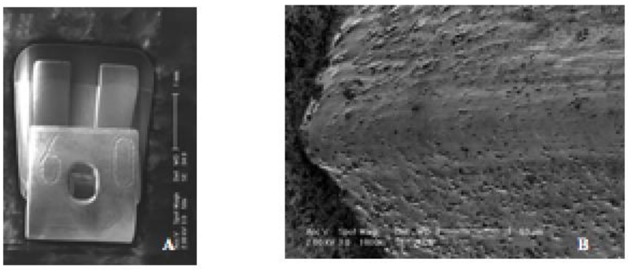
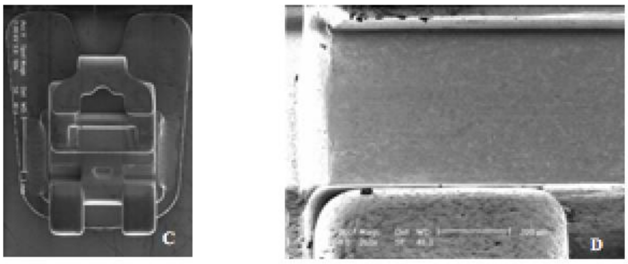
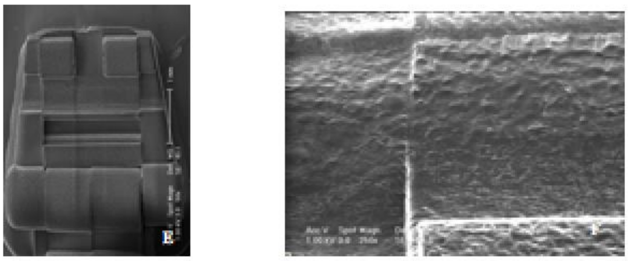
Evolution



In-Ovation L



Phantom



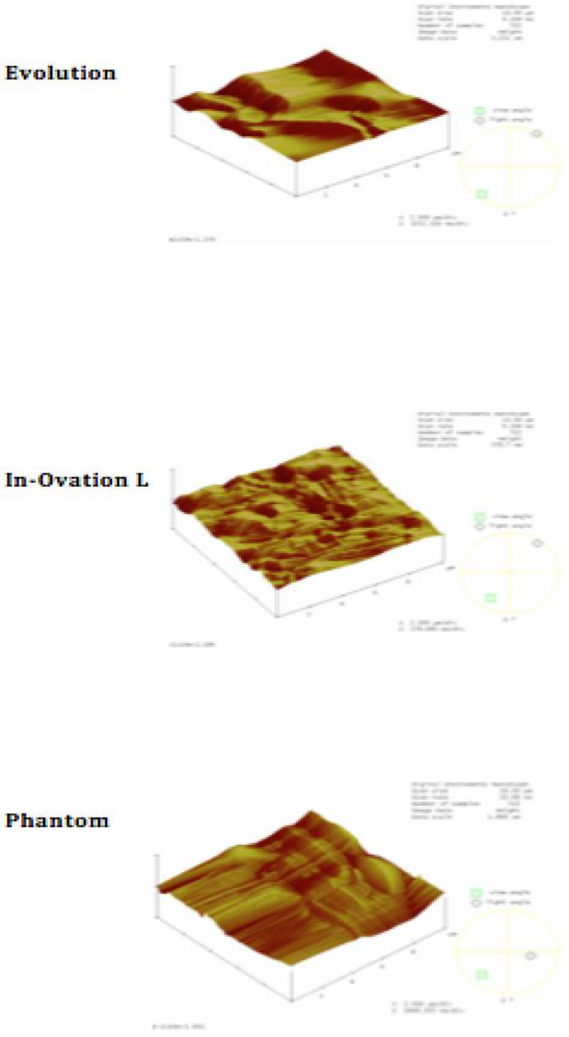


Figure 4. AFM views of the brackets.

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