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Effect of dental arch convexity and type of archwire on frictional forces

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Abstract: INTRODUCTION: Friction measurements in orthodontics are often derived from models by using brackets placed on flat models with various straight wires. Dental arches are convex in some areas. The objectives of this study were to compare the frictional forces generated in conventional flat and convex dental arch setups, and to evaluate the effect of different archwires on friction in both dental arch models. METHODS: Two stainless steel models were designed and manufactured simulating flat and convex maxillary right buccal dental arches. Five stainless steel brackets from the maxillary incisor to the second premolar (slot size, 0.22 in, Victory, 3M Unitek, Monrovia, Calif) and a first molar tube were aligned and clamped on the metal model at equal distances of 6 mm. Four kinds of orthodontic wires were tested: (1) A. J. Wilcock Australian wire (0.016 in, GH Wire, Hannover, Germany); and (2) 0.016 x 0.022 in, (3) 0.018 x 0.022 in, and (4) 0.019 x 0.025 in (3M Unitek GmbH, Seefeld, Germany). Gray elastomeric modules (Power O 110, Ormco, Glendora, Calif) were used for ligation. Friction tests were performed in the wet state with artificial saliva lubrication and by pulling 5 mm of the whole length of the archwire. Six measurements were made from each bracket-wire combination, and each test was performed with new combinations of materials for both arch setups ($n = 48$, 6 per group) in a universal testing machine (crosshead speed: 20 mm/min). RESULTS AND CONCLUSIONS: Significant effects of arch model ($P = 0.0000$) and wire types ($P = 0.0000$) were found. The interaction term between the tested factors was not significant ($P = 0.1581$) (2-way ANOVA and Tukey test). Convex models resulted in significantly higher frictional forces (1015-1653 g) than flat models (680-1270 g) ($P < 0.05$). In the flat model, significantly lower frictional forces were obtained with wire types 1 (679 g) and 3 (1010 g) than with types 2 (1146 g) and 4 (1270 g) ($P < 0.05$). In the convex model, the lowest friction was obtained with wire types 1 (1015 g) and 3 (1142 g) ($P > 0.05$). Type 1 wire tended to create the least overall friction in both flat and convex dental arch simulation models.

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Effect of Dental Arch Convexity and Type of Arch-wires on the Frictional Forces in Orthodontics

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Short title: Effect of dental arch convexity and arch-wires on frictional forces

ABSTRACT

Friction measurements in orthodontics are often derived from models where the brackets are placed on flat models with different straight wires. Dental arches in fact present not only straight but also convex nature at some areas of the arch. The objectives of this study were: 1- to compare the frictional forces generated in the conventional flat and convex dental arch set-up for better simulation of the clinical situation and 2- to evaluate the effect of different arch-wires on friction in both dental arch models. Two stainless steel models were designed and manufactured simulating the flat and convex maxillary right buccal dental arch. Five stainless steel brackets from the maxillary incisor to the 2nd premolar (slot size:0.22”, Victory, 3M) and a 1st molar tube were aligned and clamped on the metal model with equal distances of 6 mm. Four kinds of orthodontic wires were tested namely, Type 1: A.J. Wilcock Australian wire (0.016”, G&H Wire Company), Type 2: 0.016”x0.022” (3M Unitek), Type 3: 0.018”x0.022” (3M Unitek) and Type 4: 0.019”x0.025” (3M Unitek). Grey elastomeric modules (Power ‘O’ 110, Ormco) were used for ligation. Friction tests were performed in the wet state under artificial saliva lubrication and by pulling 5 mm of the whole length of the arch-wire. Six measurements (g) were made from each bracket-wire combination and each test was performed with new combinations of materials for both arch set-up (N=48, n=6/per group) in a universal testing machine (crosshead speed: 20 mm/min). Significant effect of the arch model ($P=0.0000$) and the wire types ($P=0.0000$) were found. The interaction term between the tested factors was not significant ($P=0.1581$) (2-way ANOVA and Tukey’s test). Convex models resulted in significantly higher frictional forces (1015-1653 g) than flat models (680-1270 g) ($P<0.05$). In the flat model, significantly lower frictional forces were obtained with Type 1 (679 g) and Type 3 wires (1010 g) than those of Type 2 (1146 g) and Type 4 (1270 g) ($P<0.05$). In the convex model, the lowest friction was obtained with Type 1 (1015 g) and Type 3 wires (1142 g) ($P>0.05$). Type 1 wire tend to create the least overall friction in both flat and convex dental arch simulation models.

Keywords: Archwire; dental arch convexity; frictional forces; kinetic friction; static friction

INTRODUCTION

Orthodontic sliding mechanics using pre-adjusted brackets is a common method of translating a tooth or a group of teeth to the right position. In particular, overjet reduction or space closure with the so-called “straight-wire techniques” is achieved by applying a distal force that makes the arch-wire slide through the slot of the brackets or the tubes on the posterior teeth.[1] Whenever sliding occurs, a frictional type of force is encountered.[2,3] The major disadvantage of the use of sliding mechanics is the friction that is generated between the bracket and the archwire during orthodontic movement. Friction is defined as the force tangential to the common boundary of two bodies in contact that resists the motion of one relative to the other.[1,3] Taylor et al.[2] defines friction as the force resisting the motion of a body relative to the other, and it operates in the opposite direction of the motion. Friction is also proportional to the normal force acting perpendicular to the direction of the motion.

The amount of friction on the other hand, is proportional to the force with which the two surfaces are pressed together and it is dependent on the nature of the surfaces in contact such as material composition or surface roughness.[4,5] The resistance to friction is characterized as either static or kinetic. Static friction is the force required to produce the initial movement and it is always stronger than the kinetic force that keeps the body in motion.[6,7] Tooth movement along an arch-wire is not continuous but occurs in a series of intermittent movements. Static friction in this context is considered to have a greater importance in orthodontic applications because it needs to be overcome with movement of each tooth. In an optimal bracket-wire combination, approximately 40 g of frictional forces must be included in the force applied to the tooth in order to initiate tooth movement.[2,3] Because the orthodontic force must overcome the frictional resistance and the resistance of the biological milieu, minimizing friction could result in reduced levels of the clinically applied force that is needed for moving the teeth. Such a reduction might shorten the treatment period and also improve anchorage control.[8] Friction between the bracket and arch-wire can cause up to 50% loss of force.[4,5,9] As a result, the desired tooth movement is slowed down or even inhibited. Frictional resistance during orthodontic treatment is a key factor in determining the force systems required for moving the teeth. However an excessive increase in orthodontic forces to overcome frictional resistance during retraction of the anterior teeth may also produce increased posterior anchorage loss.[2,10,11] Frictional resistance must therefore be kept to a minimum during sliding mechanics so that orthodontic tooth movement can be generated through optimal light forces with better patient comfort. [3]

The theoretic considerations and clinical implications of friction during sliding in orthodontics demonstrated that this type of force depends on complex variables, such as bracket types (conventional vs. self-ligating),[2,5,8] angulation of archwire to bracket,[12] arch-wire types,[13] dimensions and shape of the slot and the wire,[3,14] ligating force,[8,14] oscillating displacements,[2] repeated use of brackets,[11] and dry and wet environments.[4,15] Furthermore, it was reported that resistance to sliding or friction of an arch-wire-bracket assembly is a combined effect of 3 components namely, classical friction, elastic binding and/or physical notching.[16] On the other hand, the deformation amount of the arch-wire is dependant on the applied force and the elasticity of the wire.[1] Therefore wire types also play an important role in frictional forces.

The studies reported in the literature on friction measurements differ frequently in tested materials, methodology of the experimental design, recording technique with and without utilizing a lubricant.[5,8,15] The materials used can also differ from conventional composite, porcelain, metal brackets[18] to self-ligating ones and to various arch-wires.[3,15] During the last decade, various in-vitro techniques have been used to describe the frictional behaviour of archwire-bracket combinations.[7,8,19] The most frequently used *in-vitro* test set-up was the one developed by Kusy and Whitley.[20] The authors investigated friction between brackets and arch-wires under different environmental and mechanical conditions in a universal testing machine either in the dry or wet state.

Previous studies tried to create a clinical environment for frictional studies in order to translate the clinical situation to *in-vitro* settings.[2,8] However, to the authors' knowledge in such set-ups, the convexity of the dental arches with the sequence of brackets from incisors to the molars were not simulated. The information derived from flat models remains limited since the dental arches present convexity to some extend at some parts of the arches. It could be hypothesized that frictional forces may increase in a convex model that mimics the dental arch compared to the flat ones due to higher number of contact points between the arch-wire and the bracket as well as the possible effects of elastic ligation. Nevertheless, its impact on the results and the magnitude of frictional forces in such a set-up is not known.

Therefore the objectives of this study were twofold namely, to compare the friction generated by the conventional flat and convex dental arch set-up and to evaluate the effect of different arch-wires on frictional forces in these two models.

MATERIALS AND METHODS

The product name, manufacturer, chemical composition and batch numbers of the materials used in this study are listed in Table 1.

Dental arch models

Two custom-made stainless steel models were manufactured representing the flat and the convex parts of the dental arch (Figs. 1a-b) in order to simulate the frictional resistance in the buccal segments during incisor retraction with sliding mechanics. The flat model was designed according to the specifications described elsewhere.[1] The curvature of the convex model created correlates to the arch of a standard 0.019”x0.025” stainless steel arch-wire. This represents the approximate curve or dimension of the dental arch after levelling and aligning prior to the space closure phase of the treatment. The models consisted of a base where the brackets were situated. The base of the model could fit in the jig of the universal testing machine and can securely be clamped in position before the friction tests were performed. Both models allowed for placement of five brackets and one molar tube with a small vice device built in the model.[1] The distance between the brackets and the molar tube in both models were kept standard with 6 mm.

Brackets

The bracket specifications are given in Table 2. Brackets belonging to the individual tooth from the right maxillary arch were used representing the clinical situation in the first quadrant of the mouth. Stainless steel brackets (3M Unitek Victory Series™ APCII™ Orthodontic Products, Monrovia, CA, USA; Slot size:0.22”) designed for maxillary central, lateral incisor, canine, first and second premolars and a 1st molar tube (Victory, 3M Unitek, USA) were bonded with epoxy adhesive (Greven Epoxi-Bond, Bühl, Germany) on plexyglass blocks with dimensions of 8x8x2 mm. While bonding the brackets, a piece of straight wire (0.021”×0.028”) was gently placed in the bracket slots in order to enable the bracket slot and the molar tube aligned parallel along the plexyglass block.[1] This allowed the slot axis of the bracket to be perpendicular to the plexyglass block and at the same time avoid any possible rotations or misalignment of the bracket that may influence the unwanted friction during measurements.

Arch-wires

Four types of arch-wires were tested namely, A.J. Wilcock® Australian round wire-Special Plus Grade (0.016”) (G&H Wire Company, Hannover, Germany) (Type 1) and 0.016”x0.022” (Type 2), 0.018”x0.022” (Type 3) and 0.019”x0.025” (Type 4) wires (3M Unitek™ GmbH, Seefeld, Germany). The arch wire was then placed in the bracket slots and ligated passively to the tie wings with grey elastomeric modules (Ormolast® Power ‘O’ 110, Ormco, USA). The elastomers were placed in a conventional manner (figure-O pattern).[1] Care was taken to avoid introducing torsion into the test wire during clamping.

Testing procedures

The frictional force was evaluated 6 times[15] with each bracket-arch wire combination for both arch set-up (N = 48, n = 6 per group).

Each bracket was tested only once to eliminate the influence of wear. The friction tests were started immediately after ligation. The testing model was then securely mounted on the jig of the universal testing machine with a load cell of 100 N (Zwick ROELL Z2.5 MA 18-1-3/7, Ulm, Germany).[11] The testing machine was calibrated to measure maximum 2000 g of friction. Static friction was recorded while 5 mm[1,6] of the whole length of the wire was drawn through the brackets at a cross-head speed of 20 mm/min [1,11] and it was defined as the force needed to start the wire moving through the bracket-wire assembly. This force was measured as the maximal initial rise and was analyzed with the software program (TestXpert®, Zwick ROELL, Ulm, Germany). After each test, the testing machine was stopped, the wire-bracket-ligature unit was removed and a new assembly was placed. All tests were performed in the wet state using artificial saliva lubrication (Saliva Orthona, Kastrup, Copenhagen, Denmark) at room temperature (20±2°C). The saliva was dripped continuously onto the arch-wire-bracket couple by a peristaltic pump at a flow rate of 3mL/min.[15]

RESULTS

Significant effect of the arch model (*P*=0.0000) and the wire types (*P*=0.0000) were found. The interaction term between the tested factors was not significant (*P*=0.1581) (2-way ANOVA and Tukey’s test) (Table 3).

Convex model resulted in significantly higher frictional forces (1015±291-1653±465 g) than the flat model (680±186-1270±345 g) ($P<0.05$) (Table 4).

In the flat model, lower frictional forces were obtained with Type 1 (680±186 g) and Type 3 wires (1010±325 g) ($P>0.05$) than those of Type 2 (1146+350 g) and Type 4 wires (1370±345 g).

In the convex model, the lowest friction was obtained with Type 1 (1015±291 g) and Type 3 wires (1142±435 g) ($P>0.05$). Round Australian wire (Type 1) (0.016") tend to create the least overall friction in both flat and convex dental arch simulation models (Fig. 2).

DISCUSSION

A common way to reduce friction is by using a lubricant, such as oil, water, or grease, which is placed between the two surfaces, often dramatically lessening the coefficient of friction. In an attempt to increase the value of translational meaning of *in-vitro* studies to *in-vivo* situations, previous studies have also incorporated some lubricants such as silicone[1] or Ringer solution[5] in combination with glucose. However the most frequently used one is artificial saliva.[4,5,8,15] Lubricants to overcome friction are not always thin and therefore in this study the frictional forces were measured in the wet state. Artificial saliva as a lubricant may best simulate the situation in the oral milieu. Tselepis et al.[5] reported that lubrication with artificial saliva resulted in significantly lower frictional values than when tested in dry conditions and this finding was valid for nearly all bracket/arch-wire combinations studied. Pratten et al.[4] controversially, reported that saliva substitute increased the static friction for all combinations tested. Anderson and Quevedo,[17] however found that saliva played an insignificant role in frictional forces when the wire surfaces and the bracket slots were lubricated with this medium. The reasons for this discrepancy when compared to other studies[4,5] were attributed to the loading force between the arch-wire and the brackets, that is at lower loads, saliva acts as a lubricant but at higher loads saliva may increase friction.[17] In the latter situation, when the wire is forced out form the contacts between the brackets and the arch-wire, saliva may produce shear resistance to sliding forces. Nevertheless, since it is essential to reflect frictional resistance that may actually occur *in-vivo,* in this study, the experiments were conducted in the wet state under saliva. However the consistency and viscosity of the wet medium surely may affect the results.

This study was undertaken in order to investigate whether the frictional forces would be affected from the curvature of the dental arch as opposed to flat ones. Due to the significant difference in mean frictional forces between the both models, the first hypothesis could be accepted.

One of the determinants of friction is the angulation of the arch-wire to the bracket [12,19] that may create more contact areas or friction components that was the case in the curved model. The contact areas determine the probability of getting large wear track exposed to the environment and as a consequence, the chance of consuming more frictional energy. This eventually results in increase in the frictional forces thus also increasing the coefficient of friction.[8] Redilich et al.[7] has reported that higher frictional forces are developed when either wire size or bracket-wire angulation increase. The study was performed in a dry test set-up with only one stainless steel bracket. Since the bracket-wire angulation is higher in the curved model compared to the flat model set-up, the higher frictional forces with the former could be attributed to this reason. Nisho et al.[19] also stated that the magnitude of frictional forces are directly proportional with the angulation increase between the bracket and the arch-wire from 0° to10°. Angulation increases in the convex model therefore our results are in agreement with this study although in their study no lubrication was used and the results were again derived from one bracket only.

The increase in the size or surface area of the arch-wire may lead to an increase of the coefficient of friction.[8] However in this study, in both the flat and the convex model, Type 1 (Australian round wire) (0.016”) and Type 3 (0.018”x0.022”) wires created non-significant mean frictional forces although Type 1 had a smaller surface area. The Type 1 arch-wire tend to create the least frictional forces in both models however due to the insignificant difference with Type 3 arch-wire in both the flat and the convex model, the hypothesis can be accepted only partially. This is in agreement with the findings of Drescher et al.[21] where 0.016” Hi-T round wire and 0.016”x0.022” Hi-T rectangular wire showed virtually the same amount of friction. The reason for this was explained on the grounds that the friction depends primarily on the vertical dimension of the wire. It can also be anticipated that the involvement of the 1st molar tube might have also affected the results. The individual effect of the existence of the molar tubes should be further investigated.

From square arch-wires, Type 3 wire (0.018”x0.022”) revealed the least frictional forces in both the flat and the convex models. Our results contradict with those of Kapur et al.[10] where stainless steel brackets demonstrated higher static and kinetic frictional forces when the wire size increased. On the other hand, Al-Khatib et al.[8] found that the 0.017x0.025” stainless steel arch-wire created a lower coefficient of friction than the thicker 0.018x0.025” arch-wire when tested in dry conditions. In our study, since Type 2 and Type 4 presented not significantly different results, it cannot be affirmed that thicker arch-wires always create higher friction. Although the experimental conditions are not identical, namely the study was conducted in dry conditions but with 10 brackets in a row, and at a very low crosss-head speed, Tecco et al.[13] presented similar results where a thinner arch-wire (0.017”x0.025”) created more friction than the thicker (0.019”x 0.025”) one. In contrast, Taylor et al.[2] in a similar study found that the most dynamic friction created with one bracket followed by two brackets and their combination with a thicker arch-wire (0.019”x0.025”) was higher than that of a thinner one (0.016”x0.022”). It is evident that orthodontic literature needs some standardization in testing methods for frictional force measurements that could be best translated to the clinical situations.

The material from which the brackets are made of also plays a role in the magnitude of frictional forces. The results of the study by Kapur et al.[10] showed that the frictional forces are greater between two surfaces of the same material kind than two surfaces of different materials. In this study although there were slight differences between the elemental compositions of the materials used, principally both the brackets and the arch wires were of stainless steel.

Another important aspect is the number of brackets used in such experiments. Previous *in-vitro* studies were conducted with minimum one[8,11,14] and maximum ten brackets[13] in a straight line. However, in this study the quadrant arch was tried to be simulated with five brackets and a molar tube making it difficult to make direct comparisons with other studies. Nevertheless, from the clinical point of view, in this set-up, the obtained range of frictional forces in both models can be considered high.

CONCLUSIONS

From this study, the following could be concluded:

1. Convex buccal dental arch model resulted in significantly higher frictional forces than those obtained with the flat model.
2. Round Australian wire (0.016”) created the least overall friction in both models yet being not significant from Type 3.
3. Among square arch-wires, Type 3 wire (0.018”x0.022”) revealed the least frictional forces in both flat and convex models.

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LEGENDS

Figures

Figs.1a-b. Five stainless steel brackets from maxillary incisors to the 2nd premolar and a 1st molar tube aligned and clamped on the **a)** flat and **b)** convex dental arch model with equal distances of 6 mm.

Fig.2. The mean frictional forces (g) for the four wire types on flat and convex dental arch models. See Table 1 for group abbreviations.

Tables

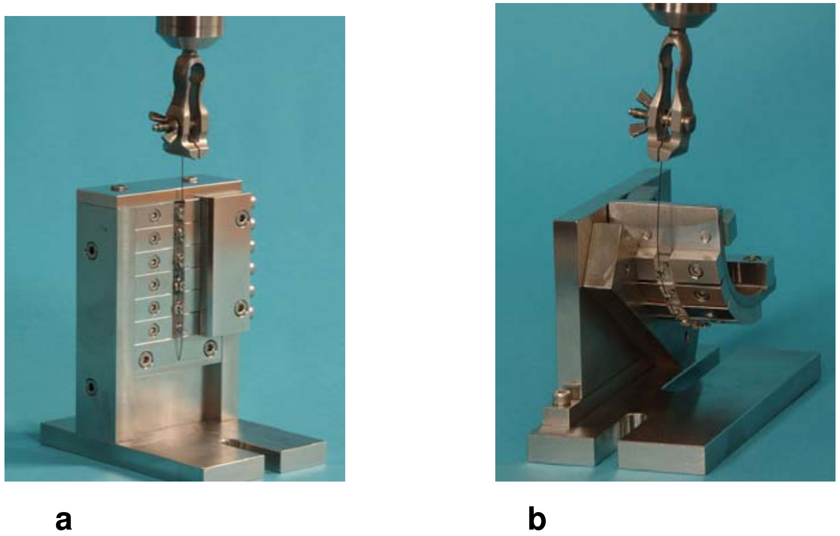
Table 1. The product name, manufacturer, composition and batch numbers of the materials used in this study.

Table 2. Features of V-Slot Brackets (3M Victory Series™) used in this study. UR= Upper Right, UNIV=Universal.

Table 3. Results of 2-way analysis of variance (ANOVA) for the flat and convex dental arch models, wire types and the interaction terms according to frictional force data. *Statistically significant difference at the level of 5%.

Table 4. The mean (±standard deviations) frictional forces (g) for arch-wire type-model combinations. The same letters indicate no significant differences ($\alpha = 0.05$). See Table 1 for the descriptions of wire types.

Figures:



Figs.1a-b. Five stainless steel brackets from maxillary incisors to the 2nd premolar and a 1st molar tube aligned and clamped on the **a)** flat and **b)** convex dental arch model with equal distances of 6 mm.

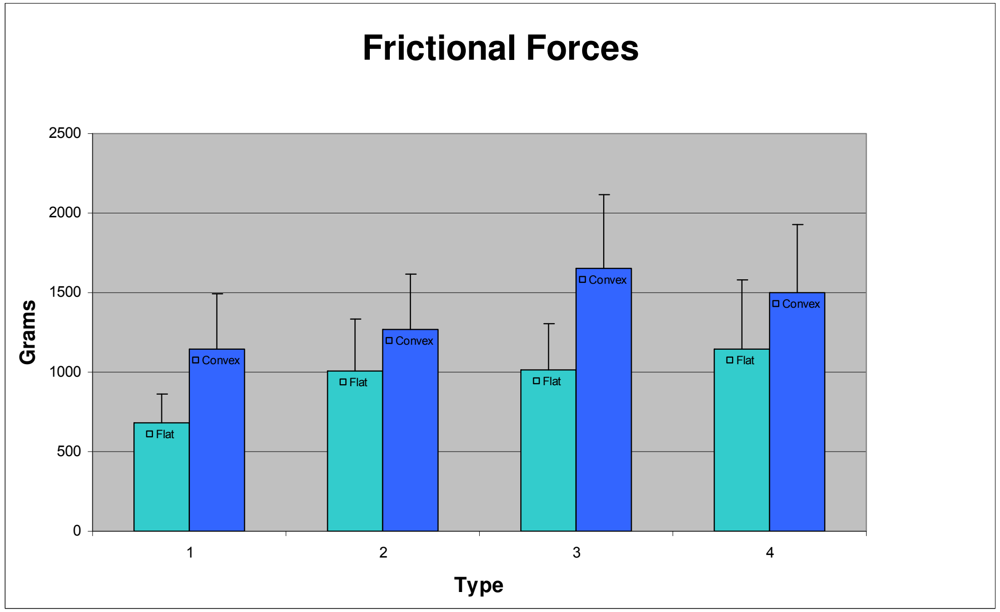


Fig.2. The mean frictional forces (g) for the four wire types on flat and convex dental arch models. See Table 1 for group abbreviations.

Tables:

Product name	Manufacturer	Chemical composition		Batch number
3M Victory Series$^{\text{TM}}$ APCII$^{\text{TM}}$ V-Slot Bracket, 0.22”	3M Unitek$^{\text{TM}}$ Orthodontic Products, Monrovia, CA, USA	C	0.08%	3017-916
		Mn	2.00%	3017-917
		P	0.045%	3017-918
		S	0.03%	3017-9200
		Si	1.00%	
		Cr	18.00-20.00%	
		Ni	8.00-10.00%	
		Fe	rest	

A.J. Wilcock® AUSTRALIAN WIRE Special Plus Grade (0.016”) **(Type 1)**	G&H Wire Company, Hannover, Germany	Fe balanced Cr 18% Ni 9% Mn 2% Co 0.75%	AW231-330
0.016”x0.022” **(Type 2)** 0.018”x0.022” **(Type 3)** 0.019”x0.025” **(Type 4)**	3M Unitek™ GmbH, Seefeld, Germany	C 0.08% Mn 2.00% P 0.045% S 0.03% Si 1.00% Cr 18.00-20.00% Ni 8.00-10.00% Fe rest	300-017 300-024 300-028
Ormolast Power O’ 110, elastomeric modules	SDS Ormco, Glendora, CA, USA	Polyurethane elastomer	637-2110
Saliva Orthana	Castrup, Copenhagen, Denmark	Xylotol (E967), methylparabeen (E218), benzalkoniumchloride, dinatrium EDTA, hydrogen peroxide	RVG 13240
Greven Epoxi-Bond	UHU GmbH & Co KG, Bühl, Germany	Epoxy resin	6116

Table 1. The product name, manufacturer, composition and batch numbers of the materials used in this study.

	Torque	Angle	In/Out	Type	0.22”
Central incisor	+14°	5°	1.22	UR	3017-914
Lateral incisor	+7°	8°	1.45	UR	3017-916
Canine	-3°	10°	1.07	UR	3017-918
Premolarx2	-7°	0°	1.09	UNIV	3017-9200
Molar tube	-14°	10°		UR	3068-9982

Table 2. Features of V-Slot Brackets (3M Victory Series™) used in this study. UR= Upper Right, UNIV=Universal.

Source of variation	DF	SS	MS	F	*P*
Model types	1	1095354	1095354	25.98	0.0000*
Wire types	3	2548876	849625	20.15	0.0000*
Interaction (Model*Wire)	3	230905	76968	1.83	0.1581
Error	40	1686732	42168		
Total	47	5561867			

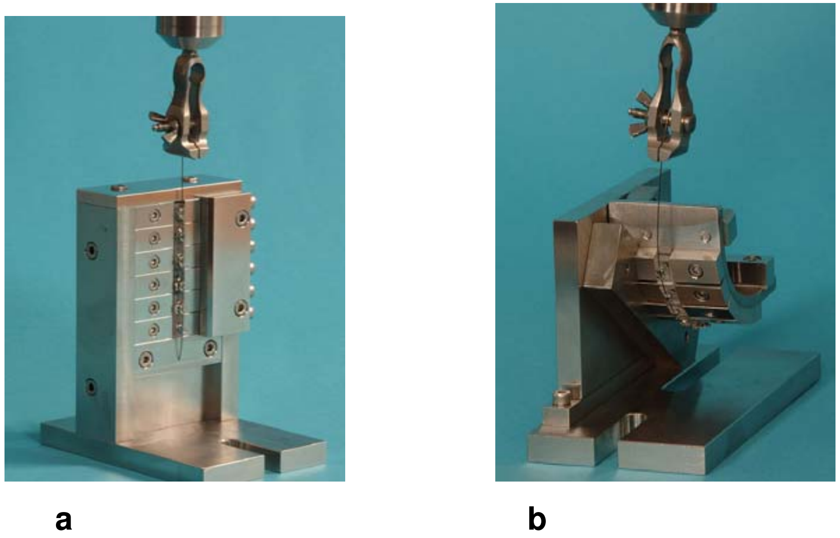
Table 3. Results of 2-way analysis of variance (ANOVA) for the flat and convex dental arch models, wire types and the interaction terms according to frictional force data. *Statistically significant difference at the level of 5%.

	Wire type	Mean(+SD)	Homogeneous groups
Flat model	**Type 1**	690±186	D

	Type 2	1146±350	B C
	Type 3	1010±325	C D
	Type 4	1270±345	B C
Convex model	**Type 1**	1015±291	C D
	Type 2	1653±465	A
	Type 3	1142±435	B C
	Type 4	1503±422	AB

Table 4. The mean (±standard deviations) frictional forces (g) for arch-wire type-model combinations. The same letters indicate no significant differences (α = 0.05). See Table 1 for the descriptions of wire types.

Figures:



Figs.1a-b. Five stainless steel brackets from maxillary incisors to the 2nd premolar and a 1st molar tube aligned and clamped on the **a)** flat and **b)** convex dental arch model with equal distances of 6 mm.