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ISSN No: 2319-5886

International Journal of Medical Research & Health Sciences, 2018, 7(3): 115-121

The Effect of Wire Dimension, Type and Thickness of Coating Layer on Friction of Coated Stainless-Steel Arch Wires

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ABSTRACT

Background/Purpose: *Esthetic coated arch wires are the desired types to match esthetic brackets in the clinical orthodontics, but the presence of coating layer is greatly affect friction during sliding mechanics. The aims of this study were to evaluate the effect of total wire dimension with the type and thickness of coating layer on friction of coated stainless-steel wires.* ***Methods:*** *The sample of this study consisted of 140 segments of coated stainless-steel arch wires involving two wire dimensions (0.016 × 0.022 inch and 0.019 × 0.025 inch). The samples were supplied from seven companies (DB, RMO, TP, DANY, G&H, Highland and Hubit) and the uncoated control samples were supplied from IOS company. Wire dimensions and thickness of coating layer were measured by the metallurgical light incident microscope and the static frictional force was measured using pulling the wire through set of ceramic brackets by the universal testing machine. The data were then statistically analyzed using ANOVA tests.* ***Results:*** *Generally measured wire dimensions do not match the stated dimensions by the manufacturer. The frictional forces of coated wires differ from uncoated control being higher in the labially coated wires and lesser in the fully Teflon coated wires owing to differences in the wire dimension, thickness of coating layer, and physical properties of coating materials.* ***Conclusion:*** *when tested in vitro, Teflon fully coated wires produce the least amount of friction.*

Keywords: Coated arch wires, Static frictional resistance force, Coating thickness, Wire dimensions

INTRODUCTION

The aesthetic appearance of orthodontic appliance is considered as an important factor for patients seeking orthodontic treatments, therefore several efforts have been made to develop different aesthetic arch wires and aesthetic brackets [1].

The manufactures are routinely used different types of coating materials to coat stainless steel or nickel titanium wires such as Teflon, Epoxy, polymer, and rhodium materials [2]. The presence of coating layer is likely to influence the mechanical and frictional properties of arch wires [3,4]. Therefore, the manufacturers always try to coat the wires with a material that present a perfect aesthetic and frictional properties [5].

Friction is defined as the resistance to movements of two or more contacting objects or the force of resistance to movements [6,7]. The frictional forces in clinical orthodontics are considered as a primary concern since it resists normal tooth movements [8]. During sliding movements of teeth, the wire edges contact the bracket angles and a frictional force will develop that compete with normal tooth movements and decrease the magnitude of applied orthodontic forces [9]. The frictional forces that are developed between polymeric aesthetic arch wires produce a binding of the wire during movements leading to increased friction between wire and bracket slot [10].

Some researchers have investigated that frictional forces of aesthetic orthodontic wires focused on the link with the surface roughness of coating layer of coated arch wires [11]. Rhodium and Teflon coating materials are the most common surface treatment that are used to coat stainless steel and nickel titanium orthodontic arch wires, rhodium coated types have increased surface roughness and consequently increased friction while Teflon coated wires have a smoother surface and therefore showing the least amount of friction therefore improved sliding movements will be obtained [12,13].

Friction is a multifactorial subject that is affected by several physical and biological factors such as arch wire dimension, shape, and materials. A small arch wire size produces less friction than larger arch wire because of the larger elasticity and the increased free space that is present between arch wire and bracket slot, and that friction is increased with rectangular wire than with round wires [14,15].

Saliva, masticatory functions and presence of food debris and calculus are the biological factors that are greatly influence the amount of friction by affecting the surface roughness and sliding movements, these factors dose not normally found in experimental conditions [16,17]. In order to control friction in clinical orthodontics, many frictionless methods and modifications can be used such as using self-ligating brackets, ion implanted TMA wires or using frictionless elastomeric ligatures [18-20].

MATERIALS AND METHODS

Samples

Seventy segments of coated stainless-steel wires from seven companies (DB, RMO, TP, DANY, G&H, Highland and Hubit) with two wire dimension 0.016 × 0.022 inches and 0.019 × 0.025 inches were used for measuring wire dimension and thickness of coating layer (five wires for each dimension). The same number of coated wires were used for the frictional resistance tests. Control uncoated wire samples were supplied from IOS company. All details of coated wires are listed in Table 1.

Table 1 Coated stainless-steel arch wires with specific details

Brand name	Type of coating	Coated surfaces
DB Orthodontics	Teflon	Labial surface
Rocky Mountain	Teflon	Labial surface
TP Orthodontics	Polymer	Labial surface
DANY	Polymer	All surfaces
G&H Orthodontics	Epoxy-resin	All surfaces
Highland Metals	Epoxy-resin	All surfaces
HUBIT	Teflon	All surfaces

A group of 48 maxillary right premolar ceramic brackets (Hubit) with a 0.022 slot were selected for the test. Ligature elastics were supplied from Opal company. Sixteen custom-made aluminum blocks (one for each brand size) with dimensions of 40 mm × 15 mm × 9 mm where used.

Devices

Metallurgical light incident microscope was used for measurement of wire dimensions and thickness of coating layer. Computerized Intron Tenuis Olsen testing machine with a load cell 10 Newton (N) was used for measurement of static frictional resistance forces.

Procedures

Total wire dimension of coated wires was measured by placing the wire segment under the microscope lens (10x magnification) from both sides of the wire (width and height), then by using the attached computerized software, the dimension can be determined in micrometer unit which were converted into inches unit. Then the wire was burned to remove the coating material and measured again under the microscope. The thickness of coating layer was calculated by subtracting the inner core dimension from the total wire dimension. This was done for each wire segment (Figure 1).

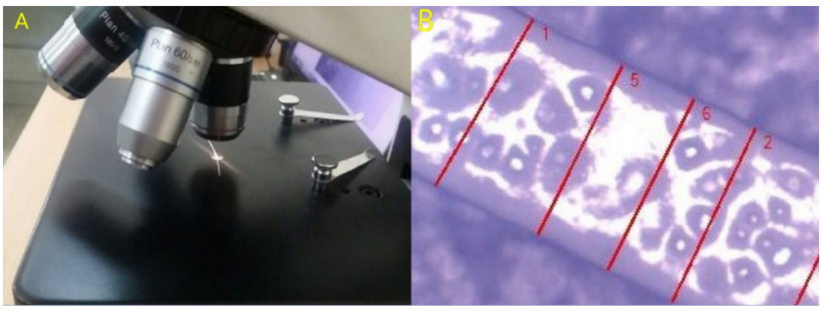

Figure 1 (A) Wire segment under microscope lens; (B) Wire as it appeared in the computer display

Coated arch wires were prepared for the frictional resistance test, the wires were cut from the straight posterior ends to a length of 50 mm using a ruler and wire cutter.

Every three brackets were fixed to the aluminum blocks with the use of bracket holder and cyanoacrylate adhesive in a straight alignment with inter-bracket distance of 8 mm with the aid of a custom-made plastic template and a straight stainless-steel wire segment of 0.0215 × 0.025 inch to properly reproduce the same angles and locations of brackets (Figure 2).

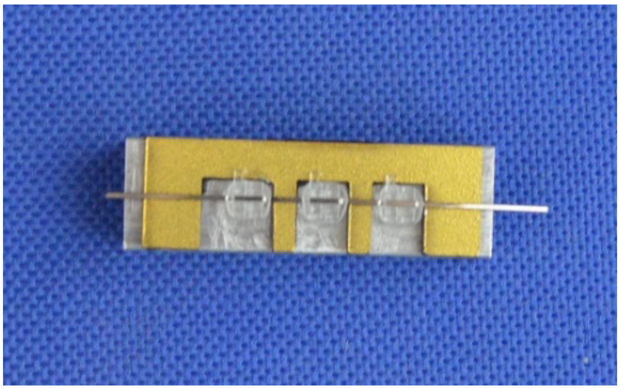

Figure 2 The setting of brackets

Every wire segment was ligated to the set of brackets for measurements of static frictional forces, ligation was done with the use of an artery forceps. Hand gloves and tweezer were used to avoid contamination of wire surfaces.

By the universal testing machine, a tensile test was used, the aluminum blocks with the adhered brackets and ligated wire was griped firmly by the lower jaw of the testing machine and the end of the wire was attached to the clamp of upper movable part (Figure 3).

Figure 3 Wire-bracket-block system fixed to machine

The specification of this test was done according to many studies [1,21,22] and as follows:

- The crosshead rate of the machine was set at 5 mm/min
- The wire was pulled through a distance of 5 mm
- For every group of wires two bracket-block combination were used and every block was used five times to exclude any expected wearing of brackets and the wires were used only once.

A load extension curve was displayed in the attached computer with the required static frictional forces measured in Newton which was then converted into gram (gm) unit. The collected data was then statistically analyzed using the descriptive statistics (mean and standard deviation) for wire dimensions. For the frictional resistance readings, ANOVA test was also used for comparison among different types of wires.

RESULTS

Table 2 illustrate the mean and standard deviation (SD) of the measured wire dimensions (width and height) and Table 3 shows the thickness of coating layer from both sides of wires, all readings are measured in thousands of inches unit (mil) for easy understating. The labially coated wires (DB, RMO and TP) show an increased dimension due to the additional coating layer that is ranged from 1.0 to 1.4 mil. The fully coated wires from DANY show a total wire dimension larger than the stated size by 0.9 to 1.3 mil with a coating thickness 0.3 to 0.6 mil. The fully coated wires from G&H and Highland have a smaller wire dimension than the stated one by 2 to 2.3 mil for GH and 2.1 to 2.3 mil for Highland and coated by ununiformed thickness that is ranged from 0.44 to 0.65 mil coating for GH and 0.35 to 0.5 mil coating for Highland.

Table 2 Means, standard deviations of dimensions of wire used in the present study

Product	0.016 × 0.022 inch		0.019 × 0.025 inch	
	Width	Height	Width	Height
Control	22.0 ± 0.052	15.8 ± 0.034	24.9 ± 0.012	18.9 ± 0.039
DANY	23.3 ± 0.029	16.9 ± 0.020	26.2 ± 0.038	20.0 ± 0.017
GH	21.3 ± 0.023	14.4 ± 0.035	25.4 ± 0.014	17.8 ± 0.038
Highland	20.9 ± 0.044	14.4 ± 0.020	25.0 ± 0.013	17.6 ± 0.007
Hubit	21.8 ± 0.076	15.7 ± 0.044	25.1 ± 0.019	19.4 ± 0.010
DB	23.5 ± 0.078	15.8 ± 0.012	26.1 ± 0.008	18.9 ± 0.006
RMO	22.8 ± 0.20	16.0 ± 0.061	26.1 ± 0.021	19.2 ± 0.008
TP	23.3 ± 0.110	15.8 ± 0.074	26.3 ± 0.007	18.7 ± 0.007

Table 3 Means, standard deviations of thickness of dimensions of wire used in the present study (*labially coated wires)

Product	0.016 × 0.022 inch		0.019 × 0.025 inch	
	Width	Height	Width	Height
DANY	0.636 ± 0.016	0.341 ± 0.007	0.567 ± 0.019	0.391 ± 0.014
GH	0.658 ± 0.092	0.375 ± 0.023	0.446 ± 0.012	0.490 ± 0.019
Highland	0.506 ± 0.035	0.353 ± 0.004	0.468 ± 0.017	0.426 ± 0.011
Hubit	0.293 ± 0.043	0.301 ± 0.019	0.256 ± 0.014	0.317 ± 0.009
DB*	1.248 ± 0.051	-	1.056 ± 0.029	-
RMO*	0.943 ± 0.077	-	1.161 ± 0.022	-
TP*	1.412 ± 0.111	-	1.350 ± 0.014	-

The means for all wires of 0.016 × 0.022 arch wires ranged from 246.8 gm for Hubit wires to 464.0 g for TP wires and from 344.0 g (Hubit wires) to 534.8 MPa (TP wires) for 0.019 inch × 0.025-inch arch wire. ANOVA test for both wire dimensions showed a highly significant difference between wires. Friction was higher for the labially coated wires TP, DB and RMO in descending order; being larger than the uncoated control wires for both wire dimensions. However, the four fully coated wires (Dany, Highland, GH and Hubit in descending order) showed less friction than the uncoated control wires for both wire dimensions (Table 4).

Table 4 Descriptive statistics and ANOVA of 0.016 × 0.022 and 0.019 × 0.025 arch wires

Samples from company	0.016 × 0.022 inch			0.019 × 0.025 inch		
	Descriptive statistics		Comparison	Descriptive statistics		Comparison
	Mean (gm)	SD	ANOVA	Mean (gm)	SD	ANOVA
Control	368.621	9.668	F=205.4 df=5 p=0.000	450.197	5.971	F=176.2 df=5 p=0.000
DANY	335.481	14.025		446.118	15.951	
GH	286.365	7.856		389.695	14.838	
Highland	301.831	12.236		383.917	9.046	
Hubit	246.767	8.889		343.978	9.271	
DB	384.256	9.596		492.005	7.145	
RMO	377.628	10.087		476.199	5.945	
TP	463.963	16.315		534.832	18.066	

DISCUSSION

In this study, the static frictional forces are measured instead of kinetic frictional force since the static friction is more appropriate in clinical orthodontic as the movement of teeth is not continues [8]. The inter-bracket distance was selected as 8 mm which is equal to the inter-bracket distance between the maxillary premolars. In the present study, ligature elastics were used instead of ligature wire in order to standardize the force magnitude [23].

None of the measured coated wires were equal the stated dimensions by the manufacturer, the fully coated wires (G&H, Highland and Hubit) show smaller dimension because the manufacturer use a smaller inner core stainless steel to compensate for the thickness of coating layer, the fully coated wires from DANY showed larger width and height, while the labially coated wires showed increased width due to the additional coating layer. This variation in standardization of dimensions was previously concluded by many studies [24,25]. The thickness of coating layer differed among brands being of 0.3 to 0.6 mil in fully coated wires and 1.0 to 1.4 mil in labially coated wires.

The present study revealed that the static friction is increased with larger wire dimension which is agree with most studies [13,26]. On the other hand, another study found that smaller arch wire will produce more friction than larger wires and attribute that to greater tipping of teeth during movements, however teeth tipping was not measured in the present study [27].

The maximum static friction was appeared with the labially coated wires since they have the larger width due to the additional coating layer which is about 1.0 to 1.4 mil. Despite the larger dimension of the fully coated wires from DANY, their values were lower than labially coated and uncoated wires, these results may be the cause of thin coating layer (0.3-0.6 mil) as compared to greater thickness of labially coated wires or may be due to the surface characteristics of polymer coating layer.

The least values were with the fully coated wires and these findings may be attributed to the decreased total dimension of these wires. To compare between the four fully coated types, G&H and Highland coated wires have nearly the same values since they have nearly the same decreased dimensions and coated with Epoxy materials. Hubit coated wires showed the least amount of friction and this may be attributed to the very thin coating layer (0.29 to 0.3 mil) or due to the physical characteristics of Teflon materials. Low friction of thin Teflon was previously demonstrated [28,29]. In addition to dimension, type and thickness of coating layer, friction can also be influenced by many other factors such as surface roughness, creep, relaxation, manufacturer processing and modulus of elasticity [2,22].

CONCLUSION

According to the present findings, generally, measured wire dimension dose not match that stated by the manufacturer and the frictional forces was greatly affected by the dimension of wire and the thickness of coating material being larger in the labially coated wires due to increased wire size and coating thickness and smaller in the fully coated wires due to decreased total dimensions and thin coating thickness.

DECLARATIONS

Conflict of Interest

The authors declare that there are no potential conflicts of interest related to the study.

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