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Friction between different wire bracket combinations in artificial saliva – an *in vitro* evaluation

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ABSTRACT

Objective: The objective this work was to assess the friction coefficient between brackets and wires of different materials under conditions simulating the oral environment. Material and Methods: Stainless steel (SS) and titanium-molybdenum alloy (TMA) wires of 0.019x0.025-in diameter (American Orthodontics) and polycarbonate bracket (American Orthodontics), ceramic bracket (American Orthodontics), and metal bracket (3M Unitek) with slots of 0.022x0.030-in were used. The friction coefficient was assessed by means of mechanical traction with the system immersed in artificial saliva. The mean roughness of both wire surface and bracket slots was evaluated by using a surface profilometer. Results: The system using TMA wire and polycarbonate bracket had the highest roughness ($p<0.05$). SS wire with ceramic bracket had the highest friction coefficient, whereas the use of metallic bracket yielded the lowest ($p<0.05$). However, it was observed a statistically significant difference in the system using TMA wire and ceramic bracket compared to that using TMA wire and polycarbonate bracket ($p=0.038$). Conclusions: Ceramic brackets in association with SS wire should be judiciously used, since this system showed a high friction coefficient.

Key words: Friction. Tensile strength. Orthodontic brackets. Orthodontic wires. Topography.

INTRODUCTION

A successful orthodontic movement is directly related to the ability of orthodontic wires to slide through brackets slots and tubes, and it is well known that the sliding resistance between the bracket slot and archwire can drastically influence the tooth movement[3,22]. The sliding mechanism is important not only to close the space, but also in the initial phase of the treatment in which leveling and alignment of the teeth occur[9].

In an attempt to fulfill an increasingly aesthetic demand, aesthetic accessories consisting of different materials have been developed, among which are the aesthetic ceramic and polycarbonate brackets[11]. Therefore, these accessories alleviate the aesthetic problem despite the limitations of their use, such as fracture of the brackets, abrasion of antagonist teeth and, mainly, the increased friction resulting from the mechanical sliding[24,26]. Friction is defined as the force opposing the movement of two objects in direct contact to each other, and its direction is tangent to a common interface between both surfaces. The intensity of this force is closely related to the surface characteristics and properties of the materials involved[1,23]. Therefore, knowing the influence of different materials on the sliding mechanism, the aim of this study was to assess the frictional force existing between conventional and aesthetic brackets in association with stainless steel (SS) and titanium-molybdenum alloy (TMA) wires by correlating the mean roughness values of wires and bracket slots.

MATERIAL AND METHODS

Materials

Conventional right upper canine brackets (B) made of pure polycarbonate (PB; American Orthodontics, Sheboygan, WI, USA), ceramic (CB; American Orthodontics, Sheboygan, WI, USA), and SS (SSB; 3M Unitek, Monrovia, CA, USA) with slots

Bracket/Wire	Stainless steel	TMA
Metallic	SSB-SS	MB-TMA
Ceramic	CB-SS	CB-TMA
Polycarbonate	PB-SS	PB-TMA

Figure 1- Systems assessed and their respective abbreviations

of 0.022x0.030-in were used for study. SS and TMA wires (American Orthodontics), both measuring 0.019x0.025-in, were evaluated (Figure 1).

Mechanical Traction Test

A device for mechanical test was developed in order to simulate the sliding movement of the wire through the bracket slots as seen during the orthodontic treatment. This device consisted of a glass box with a support centrally positioned. Holes were perforated in this glass support to fit high-rotation penholders (Dabi Atlante, Ribeirão Preto, SP, Brazil) into which the brackets were inserted (Figure 2A). The penholders were filled with self-curing composite (3M Unitek, São Paulo, SP, Brazil), thus creating a base for bonding the brackets. The brackets were then positioned and bonded to their respective penholders by using cyanoacrylate ester (Super Bonder; Loctite, São Paulo, SP, Brazil) (Figure 2B). This set was hold within the glass box through lateral rods made from glass lamina in order to keep the system stable enough during the traction test. The glass box was designed to keep the system immersed in artificial saliva, thus providing a better simulation of the oral cavity. Also, a heater with thermostat was added to this system so that the inner temperature was maintained at 37°C during the whole experiment.

A rectified 8-cm segment from both orthodontic wires was attached to the universal testing machine (EMIC DL 10.000; São José dos Pinhais, PR, Brazil), mounted onto the bonded bracket with no active torque and then tied to it with an elastic thread (3M Unitek, USA) by using a ligature elastic applicator (Morelli, Sorocaba, SP, Brazil).

The universal testing machine simulated the sliding movement of the bracket through the orthodontic wire during the retraction movement of the canines, which yielded a total dislocation of 8 mm that corresponds to the mean width of a premolar.

A personal computer connected to the equipment recorded graphic results showing values of maximum load (N) generated by a load cell. Such a test was repeated 5 times for each of the 3 combinations of bracket/wire of each group.

Surface Roughness

The wings of the brackets were removed with a steel diamond discs (22-mm diameter, 0.15-mm thickness, ref. 7016, KG Sorensen, São Paulo, SP, Brazil) at low speed on a handpiece (Dabi Atlante) for reading through a profilometer (Surf Test SJ, 201, Mitutoyo Co., Kawasaki, Honshu, Japan). Three milliliters of slots of the 3 types of brackets were analyzed, yielding three readings for each bracket. Similarly, 5-mm segments of each wire submitted to mechanical traction test were sectioned, and 3 mm of them were analyzed, also yielding three readings for each wire.

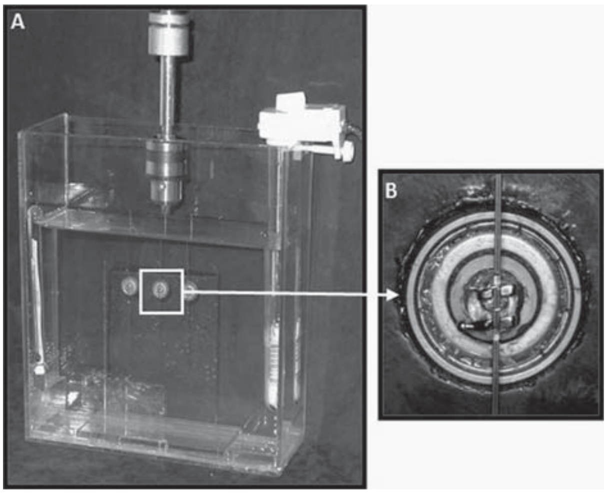

Figure 2- A) Device made for stabilizing the combinations of bracket and wire during mechanical test. B) Detail of the bracket moving through the wire and angulation close to 0°

Scanning Electronic Microscopy (SEM)

The orthodontic brackets and wires were randomly selected, and sectioned for analysis of their surface with a JEOL scanning electron microscope (2000 FX, Tokyo, Japan). The samples were separately washed with isopropylic alcohol for 5 min. Next, the orthodontic bracket and wires were positioned on a double-faced adhesive tape whose sequence was carefully recorded. The samples were then placed in the sample chamber of the microscope for visualization of the surfaces of the bracket slots and wires.

Statistical Analysis

The data obtained were submitted to simple ANOVA with Tukey's test for *post-hoc* multiple comparison tests between the systems. Confidence interval was set at 95% ($p<0.05$).

RESULTS

SS wire had a lower mean value of roughness value compared to TMA wire. On the other hand, the polycarbonate bracket had a greater roughness compared to the ceramic and metallic ones (Table 1). The results regarding roughness of brackets and wires after be submitted to mechanical traction test demonstrated a reduction in the roughness in all materials studied, with the metallic brackets having the most significant reduction (61.7%) and the polycarbonate brackets having the lowest (47.6%).

Comparing the maximum mean friction values for the bracket systems using SS wire (Table 2), no statistically significant differences were found between metallic (SSB-SS) and polycarbonate (PB-SS) brackets. There were significant differences between the systems of ceramic (CB-SS) and metallic brackets using SS wire (SSB-SS) ($p<0.001^*$) as well comparing the systems CB-SS and PB-SS ($p=0.001$).

With regard to systems of brackets using TMA wire, no statistically significant differences were found between metallic (SSB-TMA) and polycarbonate (PB-TMA) brackets or between metallic (SSB-TMA) and ceramic (CB-TMA) brackets. However, statistically significant differences were observed between the PB-TMA and CB-TMA systems ($p=0.038$).

The SSB-SS system had the lowest friction coefficient, differing significantly from the SSB-TMA ($p=0.012$). However, when the systems PB-SS and CB-SS were compared to the systems PB-TMA and CB-TMA, respectively, no statistical differences were found.

The SSB-SS and CB-SS systems had the lowest and highest friction coefficients, respectively. Figure 3A shows that the friction coefficient tends to be even higher in the CB-SS group. On the other

Table 1- Mean values for roughness in Å. Reading regarding 3-mm segment of each sample

Condition	Wire		Bracket		
	Stainless steel	TMA	Metallic	Polycarbonate	Ceramic
New	3300	4900	13300	28600	28400
Used	1580	780	5100	14975	11333

Table 2- Statistical data on friction coefficient of the systems of bracket and wire (n=15)

System 1		System 2		Significance
Abreviation	**Friction (N)±SD**	**Abreviation**	**Friction (N)±SD**	**p-value**
SSB-SS	1.37±0.26	PB-SS	1.48±0.62	0.999
SSB-SS	1.37±0.26	CB-SS	3.20±2.01	<0.001*
PB-SS	1.48±0.62	CB-SS	3.20±2.01	0.001*
SSB-TMA	3.14±1.22	PB-TMA	2.54±0.95	0.698
SSB-TMA	3.14±1.22	CB-TMA	4.16±2.40	0.34
PB-TMA	2.54±0.95	CB-TMA	4.16±2.40	0.038*
SSB-SS	1.37±0.26	SSB-TMA	3.14±1.22	0.012*
PB-SS	1.48±0.62	PB-TMA	2.54±0.95	0.396
CB-SS	3.20±2.01	CB-TMA	4.16±2.40	0.518

Significance level of 95% (*p<0.05; ANOVA and Tukey's post hoc test). SD=Standard deviation

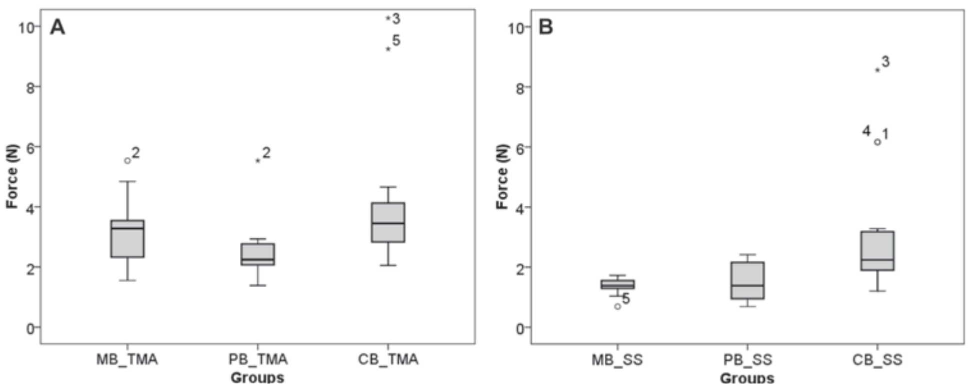

Figure 3- Box plot showing maximum frictional coefficients between metal, polycarbonate, and ceramic brackets in association with different wires: A) Stainless steel wire; B) Titanium-molybdenum alloy (TMA) wire. Simple analysis of variance (ANOVA) and Tukey's test as *post hoc* multiple comparison test at confidence interval of 95% (* p<0.05)

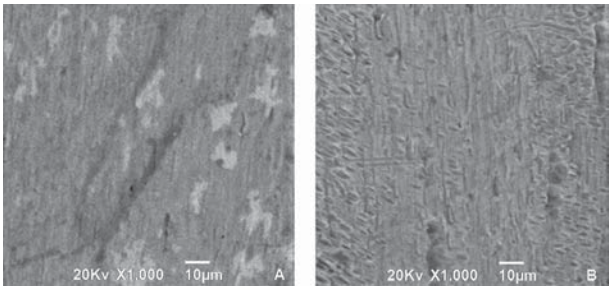

Figure 4- Scanning electron microscopy micrograph showing surface topography of TMA wire (associated with MB) before (A) and after (B) mechanical traction

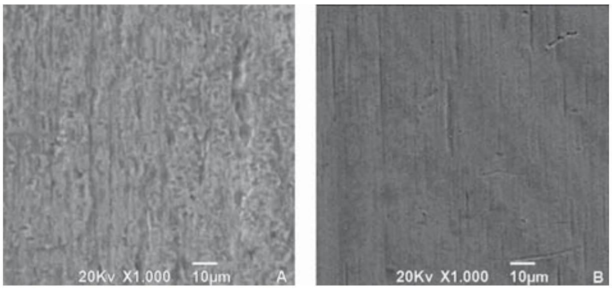

Figure 5- Scanning electron microscopy micrograph showing surface topography of SS wire (associated with MB) before (A) and after (B) mechanical traction

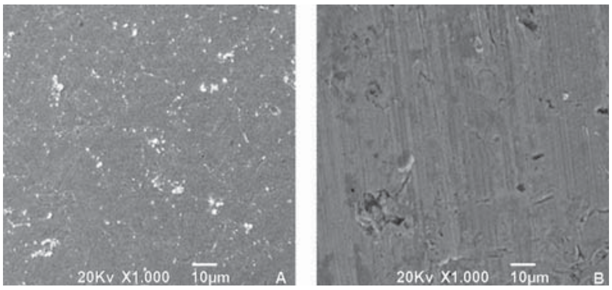

Figure 6- Scanning electron microscopy micrograph showing surface topography of MB slot (associated with SS wire) before (A) and after (B) mechanical traction

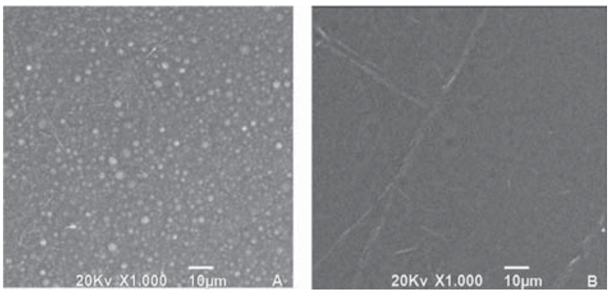

Figure 7- Scanning electron microscopy micrograph showing surface topography of PB slot (associated with SS wire) before (A) and after (B) mechanical traction

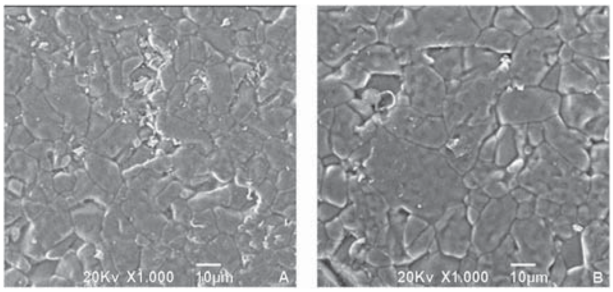

Figure 8- Scanning electron microscopy micrograph showing surface topography of CB slot (associated with SS wire) before (A) and after (B) mechanical traction

hand, the PB-TMA system had the lowest friction coefficient, followed by the SSB-SS and CB-TMA systems, with the highest friction coefficient among all systems (Figure 3B).

The TMA wire (Figure 5A, B) has less smooth surfaces compared to SS wire (Figure 4A, B). The conventional metallic bracket (Figure 6A, B) also exhibits a smoother surface than the polycarbonate (Figure 7A, B – polymers homogeneously distributed) and ceramic (Figure 8A, B – the most irregular surface among all) brackets.

After the mechanical traction test, the surfaces of all materials studied were more polished, which was more evident in the polycarbonate brackets and less evident in the ceramic brackets.

DISCUSSION

The friction on a given surface is closely related to both material involved and surface characteristics[4,10,14,15]. With regard to roughness, the SS wire exhibited less irregular surface compared to that of TMA wire, thus corroborating other findings in the literature[16,18] and confirming that the greater the roughness, the higher the friction coefficient[22]. In the present study, the systems using TMA wire had a higher friction coefficient regardless of the type of bracket used. In addition, TMA has been shown to present lower modulus of elasticity, springback greater than that of steel[8]. With regard to the brackets, the slots of metallic brackets exhibited less roughness compared to those of polycarbonate and ceramic ones. However, the polycarbonate bracket showed a friction coefficient lower than that of ceramic bracket either with SS wire (p=0.01) or TMA wire (p=0.038), both statistically significant. This may be explained by the fact that the profilometer could not detect small irregularities which were easily observed in the SEM images, and the ceramic bracket showed more irregularities than the polycarbonate accessory, thus justifying the similarity of roughness between SS and TMA wires.

The authors developed an apparatus that was immersed in artificial saliva during mechanical traction test, which not only reduces the friction but also simulates the sliding mechanism as seen *in vivo* and control an important variable, the lubrication[21,28]. Furthermore, studies demonstrated that lubrication reduces significantly the friction between bracket and wire[14,23,27,28]. Also, a device was developed to correct the small vertical angulations so that the angle formed between wire and bracket was close to 0°, thus helping to reduce the friction coefficient. According to the literature, friction coefficient increases as the angulation between bracket and wire increases[20, 29].

Generally, when extraction is indicated during orthodontic treatment, closing of extraction spaces can be performed mainly by canine retraction through distal movement[13]. For this reason, canine brackets were selected for the present study. Wire was attached to the bracket with elastic ligatures because it promotes an additional force in comparison to wire ligature[2,12]. In addition, attachment to the bracket with elastic guarantees a standard force in comparison to the wire ligature.

The different combinations comparing the SSB-SS and PB-SS systems showed that both yielded the lowest friction coefficients without statistically significant differences. This fact is explained by the use of brackets and wires made from the same material, which reduces friction as surfaces from the same material tend to have less friction compared to surfaces from different materials, in addition to their low roughness compared to other groups. With regard to the PB-SS system, despite using different materials, the low friction coefficient observed may be explained by the fact that the polymeric chains (macromolecules consisting of simple molecules) are small spheres homogeneously distributed on the surface of the polycarbonate bracket, being partially responsible for its roughness. These factors may explain the lack of statistically significant difference in the low friction coefficient between these both systems.

On the other hand, the CB-SS system had the highest friction coefficient, being statistically significant different from the SSB-SS system, which is also in agreement with the literature[5,19,30]. This can be explained by the higher surface roughness of the ceramic brackets and also by the different wire material (SS)[26], thus making the sliding movement of the bracket through the wire difficult. In addition, the ceramic bracket showed higher friction coefficient compared to the polycarbonate bracket, since the former consists of crystal grains that are clearly larger than the monomers of the polycarbonate. As can be seen in the SEM images, the ceramic surface also exhibits more irregularities, thus increasing the friction.

Similarly, no statistically significant difference between polycarbonate and metallic brackets was found when they were used in combination with TMA wire, with both systems having a lower friction coefficient. Significant difference was observed in relation to the ceramic brackets (p=0.038), but not between metallic and ceramic brackets. This is due to the fact that both ceramic bracket and TMA wire have higher friction coefficients because they have a rougher topography compared to other systems. However, no statistically significant difference was observed between polycarbonate and metallic brackets regarding the friction coefficient because of the increased friction observed in relation to the SS wire.

The TMA wire allows flexibility and short-range movements[16]. However, even in the final phases of the treatment in which the long-range movements are not the main goal, TMA wire should be carefully used as the results of the present study have shown that its friction is significantly higher than that of SS wire for metallic brackets, a finding also corroborated elsewhere[6,7]. However, when polycarbonate and ceramic brackets are used in combination with TMA wire, the friction coefficient decreases compared to systems using SS wire. It is suggested that despite the brackets being of different materials and TMA wire having a rougher surface compared to SS wires, it is possible that the flexibility of the TMA wire might have produced less friction, reducing the frictional resistance for small inclination angles, although the brackets were in a rotating platform. Therefore, no statistically significant difference between metallic and polycarbonate brackets was observed, whereas significant difference was found between the polycarbonate and ceramic brackets. This latter system also showed higher friction coefficient compared to the other systems, but with no statistically significant difference.

One can observe that the SS wire has a lower friction coefficient when used with metallic bracket compared to the TMA wire, which is well described in the literature[17,25]. As the materials composing brackets and wires of each system are different, no significant differences between the systems using polycarbonate and ceramic brackets in association with SS and TMA wires were observed.

The orthodontic brackets and wire submitted to mechanical traction tests were then evaluated by using a profilometer in order to verify changes on the surface. The results showed a decrease in the roughness of all materials tested: SS wire (52.2%), TMA wire (84.1%), polycarbonate bracket (47.6%), ceramic bracket (60.1%), and metallic bracket (61.7%). These results were corroborated by SEM analysis.

Based on the data obtained the present study, it is important to emphasize that in sliding mechanics the effective force to be clinically applied to metallic brackets should be increased when using TMA wire instead of SS wire in order to maintain a satisfactory speed of the tooth movement. On the other hand, this increased force requires other issues to be evaluated. Some undesirable consequences such as loss of anchorage, tooth inclination, root absorption, and intense pain may occur, among other complications that may cause short- and long-term irreversible damages. Future studies are suggested to evaluate how human salivary components act on the friction between bracket and wire during orthodontic treatment.

CONCLUSIONS

The following conclusions can be drawn:

the system formed by metallic bracket and SS wire exhibited less roughness and lower friction.

the use of ceramic brackets with TMA wire should be judiciously used as this system was found to have a higher friction coefficient.

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