Original Article

Role of lubricants on friction between self-ligating brackets and archwires

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ABSTRACT
Objective: To evaluate the effect of different lubricants on friction between orthodontic brackets and archwires.
Materials and Methods: Active (Quick, Forestadent) and passive (Damon 3MX, Ormco) self-ligating brackets underwent friction tests in the presence of mucin- and carboxymethylcellulose (CMC)–based artificial saliva, distilled water, and whole human saliva (positive control). Dry friction (no lubricant) was used as the negative control. Bracket/wire samples (0.014 × 0.025 inch, CuNiTi, SDS Ormco) underwent friction tests eight times in a universal testing machine.
Results: Two-way analysis of variance showed no significant interaction between bracket type and lubricant ($P = .324$). Friction force obtained with passive self-ligating brackets was lower than that for active brackets ($P < .001$). Friction observed in the presence of artificial saliva did not differ from that generated under lubrication with natural human saliva, as shown by Tukey test. Higher friction forces were found with the use of distilled water or when the test was performed under dry condition (ie, with no lubricant).
Conclusion: Lubrication plays a role in friction forces between self-ligating brackets and CuNiTi wires, with mucin- and CMC-based artificial saliva providing a reliable alternative to human natural saliva. (*Angle Orthod.* 2014;84:1049–1053.)

KEY WORDS: Brackets; Friction; Lubrication; Human saliva; Artificial saliva

INTRODUCTION

Successful orthodontic movement is dependent on the sliding mechanism between wires, brackets, and tubes.[1] As a result of the friction established at the contact areas between the devices, higher-magnitude forces are required to obtain the desired movement.[2,3]

To optimize treatment, lower-friction brackets, namely, self-ligating, have been introduced.[4–7] These brackets are classified as active or passive.[8–12] The former have a slot-closure system that exerts pressure on the orthodontic wire,[6–8,13] while the passive self-ligating brackets have a closure system that turns the slot into a tube, in which the wire does not receive active pressure.[6–8,10,13]

Tests have been performed to measure the force and/or friction coefficient between brackets and orthodontic wires, in terms of slide resistance, to compare the systems available.[3,8–11] Research has demonstrated that the testing conditions are generally distant from the clinical situation. In fact, studies that simulate the sliding action between wires and brackets are commonly performed under dry conditions,[9,11,13–16] with no lubrication, different from what happens in the intraoral environment, where the presence of saliva acts as a lubricant.

Considering that dry friction can promote higher resistance to sliding,[1,5,17] some authors have used distilled water[1] or artificial saliva[4,17–20] to better reproduce the clinical scenario in their friction tests between orthodontic wires and brackets. Although the introduction of lubricants has added weight to these studies, the lubrication capacity of water, for example, does not compare to that of natural human saliva.[21] The same can be said for artificial saliva, which may or may not have the same rheological properties and lubrication capacity of human saliva.[22] Therefore, the presence and type of thickening agent used in the artificial saliva are of paramount importance.[22]

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Among the thickening agents, it has been reported that mucin-based saliva has rheological properties closer to human saliva, including the ability to form a superficial film,[23] which is an important feature in its efficiency as a lubricant.[21,22] On the other hand, carboxymethylcellulose (CMC) salivas containing could have an inferior capacity to form a superficial film, thus compromising their potential to simulate the lubrication obtained from natural human saliva.[24]

Considering that the contact and slide relationships observed in the oral cavity between wires and brackets occur in the presence of saliva, the validity of dry and distilled water friction tests is questionable. To understand the slide mechanisms between wires and brackets, it is essential that the experimental conditions are as close as possible to the clinical scenario. The use of human saliva could be an option, but because of its lability,[25] inconsistent results have been reported in studies directed at studying friction in the presence of this lubricant.[19] In fact, both friction reduction[26] and increase[27] have been demonstrated between wires and brackets in the presence of human saliva. Therefore, it is necessary to validate the use of alternative lubricants, such as artificial saliva, which are able to simulate human saliva and, simultaneously, overcome its limitations. There is evidence that artificial saliva can reduce bracket and wire friction by 15% to 60%.[17,18] However, the formulation of the artificial salivas used in studies is generally not specified and its rheological properties are unknown, which makes the definition of friction test protocols impracticable. Consequently, comparisons between scientific findings become substantially limited, given the absence or diversity of lubricants used.

The aim of this study was to evaluate the effect of different lubricants on the friction between a CuNiTi orthodontic wire and both active and passive self-ligating brackets.

MATERIALS AND METHODS

The experimental design was completely randomized in a 2 × 5 factorial arrangement with two self-ligating brackets (active and passive) and five lubrication conditions (no lubrication, as a negative control; natural human saliva, as a positive control; distilled water; mucin-based artificial saliva and; CMC-based artificial saliva). The combination between the levels from both study factors generated 10 experimental groups.

A sample size calculation was done, which suggested that for a two-way analysis of variance with four degrees of freedom, a minimum effect size of .4, and a significance level of .05, 10 specimens per group would be necessary to achieve a power of 90%. The experimental units were 50 active (Quick, Forestadent, Pforzheim, Germany) and 50 passive (Damon 3MX, Ormco, Glendora, Calif) self-ligating brackets with a 0.022-inch slot size, in which an orthodontic wire was placed and subjected to sliding, in the presence of one of the lubrication conditions ($n = 10$). The outcome variable was friction, measured in N.

Ethics and Natural Human Saliva Sampling

This study was approved by the local ethics committee (protocol 2011/0391). A single volunteer, who signed an informed consent form, donated the saliva used in this study. Inclusion criteria for the participant included normal salivary flow, no regular medication, no dental treatment required, no fixed or removable prosthodontics, and no orthodontic appliances. Exclusion criteria included presence of systemic disease, smoking, and use of alcohol.

Unstimulated whole human saliva was collected in the morning, 2 hours after eating and toothbrushing, and immediately before the friction tests. During collection, the volunteer remained seated, with head tilted forward, allowing saliva to flow into a funnel placed over a sterile test tube.

Artificial Saliva Preparation

Both mucin- and CMC-based artificial salivas were prepared following the formula proposed by Christersson et al.[22] The mucin-based preparation was composed of porcine mucin (3.5 g), xylitol (2 g), methylparaben (100 mg), ethylenediaminetetra-acetic acid (50 mg), benzalkonium chloride (2 mg), and sodium fluoride (0.42 mg) in 100 mL of aqueous solution. The CMC-based saliva was composed of CMC (500 mg), sodium fluoride (20 mg), xylitol (3 g), potassium phosphate (35 mg), sodium chloride (90 mg), and potassium chloride (120 mg) in 100 mL of aqueous solution.

Friction Testing

Rectangular CuNiTi (SDS Ormco) orthodontic wires, measuring 0.014 × 0.025 inches, were sectioned using cutting pliers (Orthopli, Philadelphia, Penn), in 3-cm segments to obtain 100 samples.

Each segment was placed on the holding end of a device attached to a universal testing machine (EMIC DL 10000, São José dos Pinhais, PR, Brazil), parallel to the base of the bracket slot. The bracket was bonded to a cylindrical acrylic base using a cyanoacrylate-based adhesive (Super Bonder, Loctite-Henkel, São Paulo, SP, Brazil).

The lubricant of each group was applied to the wire, next to the bracket slot, using a micropipette with a standard volume of 50 µL. The negative control group was measured under dry friction (ie, in the absence of lubrication). The universal testing machine was equipped with a 20-N loading cell to cause tension on the orthodontic wire, which moved 1 mm at a speed of 3 mm/min. Eight consecutive tests were performed for each wire-bracket set.

Statistical Analysis

Friction data were analyzed using two-way analysis of variance and Tukey test. Calculations were carried out using SPSS 20 (SPSS Inc, Chicago, Ill), with a significance level of 5%.

RESULTS

Two-way analysis of variance revealed no significant interaction between bracket type and lubrication condition ($P = .324$). The friction observed for the passive self-ligating brackets was significantly lower than that for the active brackets ($P < .001$), as observed in Table 1. A significant difference was also observed in friction among lubrication conditions ($P < .001$). Tukey test revealed that the friction values obtained using artificial saliva did not differ from those in the natural human saliva group. Significantly higher friction values were observed for distilled water and dry friction (no lubricant), with the friction values for each of them being equivalent, as shown in Table 1.

DISCUSSION

Considering that resistance to sliding can inhibit tooth movement, several studies have emphasized the understanding and minimization of friction.[5,17–19,26,28–30] In fact, one of the applications of friction tests is to evaluate the effect of using different types of brackets,[2–6,8,17,31,32] such as self-ligating.[9–15,29,30,33]

The evaluation of friction is also important to test the effect of orthodontic wires made from various alloys,[15,16,17,34] with different cross-sectional shapes (rounded or rectangular) and diameters or varied dimensions.[2,5,8,18,19,33,35] In this investigation, we chose a 0.014 × 0.025-inch rectangular intermediate CuNiTi wire, based on the fact that it is commonly used with self-ligating brackets for a prolonged time period during orthodontic treatment.

To achieve greater proximity between the results obtained from the friction test and the clinical scenario, it would be interesting if the dynamics within the oral cavity were reproduced, despite the inherent control of variables in studies in vitro. Therefore, the presence of lubricants during friction tests represents an important aspect, since saliva plays such a role on the sliding mechanics in vivo. However, most of the friction tests in the literature are performed using dry friction.[2,5,9,13–16,33–35] Although some have used artificial saliva,[4,5,17,18,20,26,27] they did not mention its suitability to simulate the rheological characteristics of human saliva. This study evaluated the effect of different lubricants, with known rheological properties, on the friction between CuNiTi wires and active and passive self-ligating brackets.

The present study demonstrated that the friction values obtained with the use of artificial saliva were not different from those observed for the natural human saliva group. This equivalence may be explained by the adsorption- and film-forming capacity of the artificial salivas.[22] Although the mucin-based saliva used presented similar viscoelasticity to human saliva[23] and also a high adsorption capacity, thus producing superior lubrication,[24] the CMC-based saliva did not perform worse than the mucin-based saliva in this study. An explanation for this finding may be found in the hydrophobic nature of the CuNiTi wire used, which confers film-forming properties to the CMC-based saliva as well.[22]

These findings have demonstrated that the artificial saliva studied has yielded similar results to human saliva, which corroborates the study by Turssi et al.,[21] in which no significant difference in lubrication capacity was observed for mucin-based artificial saliva when compared with natural human saliva in wear tests. However, in a different study, the friction obtained with artificial saliva was greater than that with human saliva, water, and dry friction.[26] This result contradicts our findings and can be attributed to the fact that the

Table 1. Friction Mean Values (Standard Deviations), in N, of the Archwires According to the Bracket and Lubricant Used[a]

Lubricant	Self-ligating Bracket: Active	Self-ligating Bracket: Passive	Grand Means
Whole human saliva	1.72 (0.40)	0.96 (0.62)	1.34 (0.62) a
Mucin-based saliva	1.77 (0.45)	0.63 (0.40)	1.20 (0.72) a
CMC-based saliva	1.57 (0.51)	1.31 (1.04)	1.44 (0.80) a
Distilled water	3.22 (1.79)	1.66 (1.02)	2.44 (1.58) b
No lubrication (dry friction)	3.50 (1.64)	2.23 (0.91)	2.86 (1.52) b
Grand means	2.36 (1.32) A	1.36 (0.95) B	—

[a] Mean followed by a capital letter indicates a difference between brackets regardless of the lubricant. Mean followed by lowercase letter indicates a difference between lubricants regardless of the bracket.

artificial saliva used may have had rheological properties that limited their capacity of adsorption and film formation. In fact, a previous investigation[24] has shown that four of the five artificial salivas used in the conflicting study by Kusy and Whitley[26] did not show lubricating action.[24]

In this study, significantly higher friction values were observed when distilled water was used or when dry friction tests (no lubricant) were performed. This can be explained by the fact that water does not form an adequately thick film between surfaces in relative movement[21] and that, under dry conditions, surface contact is increased and so is the friction. If one considers that when wire/brackets were unlubricated friction increased from 70% to 255% (Table 1) in comparison with the conditions in which natural or artificial salivas were used, it can be assumed that laboratory studies in which the sliding mechanism is performed under dry conditions seem to deviate more from in vivo conditions and thereby may be overestimating the resistance to sliding.

Considering that the friction generated with the use of mucin- and CMC-based artificial salivas was equivalent to that measured using natural human saliva, as well as the fact that they lubricate with the advantages of eliminating the need for a saliva donor and the presence of cross-contamination,[21] not to mention the difficulties with collection and storage,[27] it is important to note that both mucin- and CMC-based artificial salivas would be the lubricants of choice for friction tests between wires and orthodontic brackets.

The current findings corroborate those from previous studies, which demonstrated that passive self-ligating brackets produce less friction than active brackets,[10,13,15,29,30,34] and this occurred independently from the lubrication condition. This could be explained by the fact that passive self-ligating brackets have a clip that, when closed, creates a passive tube in the bracket slot, avoiding clip pressure onto the wire, which is the opposite to what happens with the active self-ligating brackets, in which the clip exerts pressure onto the wire.

As friction depends on materials used and testing conditions, further investigations are needed to focus, for example, on the influence of the tested lubricating conditions during sliding mechanisms when wires of varying cross-sectional sizes are used. Future research is also warranted to investigate whether the results achieved with mucin- and CMC-based artificial salivas for brackets with neutral angulation would hold under angulated conditions. In this way, it would be simulated binding phenomena, which play a primary role in the resistance to sliding in the clinical condition, that would thereby provide the understanding of the meaning of the current results on a more clinically relevant level.

CONCLUSION

- Lubrication plays a role in friction forces between self-ligating brackets and CuNiTi wires, with mucin- and CMC-based artificial saliva providing a reliable alternative to natural human saliva.

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