ORIGINAL RESEARCH

Frictional Forces of Three Types of Lingual Appliance with Self-ligating Mechanisms

Enrique E Zuñiga-Heredia[1], Takeshi Muguruma[2], Naohiko Kawamura[3], Masahiro Iijima[4]

Abstract

Aim and objective: The present study compared the frictional forces of three types of self-ligating lingual appliances.

Materials and methods: The lingual appliances (2D, Forestadent; Alias, Ormco; and Clippy L, Tomy International) consisted of a self-ligating bracket (second premolar) and two self-ligating tubes (first and second molars) bonded to a stainless steel jig and attached to a "drawing-friction tester." Full-size and non-full-size stainless steel archwires were tested, and the static and kinetic friction acting on six lingual appliance/wire combinations was estimated ($n = 5$). Three-dimensional micro-computed tomography (micro-CT) analysis of each premolar bracket was performed. The frictional forces were compared between the bracket/wire combinations using the Kruskal–Wallis and Mann–Whitney *U* tests.

Results: The Alias and Clippy L bracket/wire combinations had greater contact between the wire surfaces and bracket slots compared to the 2D bracket/wire combination. For all lingual appliances, the static and kinetic frictional forces were significantly higher for the full-size than non-full-size archwire. The 2D bracket, which had a wider outer wing, had less frictional force than the other appliances. The Alias, which had a narrower outer wing, had a significantly lower frictional force than the Clippy L.

Conclusions: Frictional force was significantly higher for heavier full-size bracket/archwire combinations than for non-full-size archwires. The 2D bracket had lower frictional force due to its archwire-holding mechanism. The outer wing width may influence the frictional resistance.

Clinical significance: The frictional forces of self-ligating lingual appliances vary, and bracket design and archwire size may influence the frictional performance.

Keywords: Friction, Lingual orthodontics, Self-ligating bracket.

The Journal of Contemporary Dental Practice (2021): 10.5005/jp-journals-10024-3093

Introduction

The increased demand for esthetic treatments has led to the development of techniques that prioritize esthetic outcomes, such as clear aligner treatment and lingual orthodontics. Since lingual orthodontics was first introduced by Fujita in the 1970s,[1] bracket design has evolved toward more comfortable and simple-to-use systems. Lingual appliances have several advantages, including good esthetics, a closer position to the center of rotation,[2] a significant reduction in white spot lesions,[3] and less anchorage loss.[4] However, lingual orthodontics also has some disadvantages, including tongue discomfort, speech difficulty, problems associated with the wide variation in tooth morphology, shorter crown height, and smaller arch perimeter.[2,3]

The orthodontic tooth movement is greatly influenced by frictional force (i.e., resistance to sliding) between the brackets and archwires.[5–7] Frictional force is influenced by bracket design (including slot size),[8,9] the mechanical properties (hardness and elastic modulus) of the archwire,[10] archwire/bracket angulation,[11] and surface roughness.[12,13] Because of anatomical limitations and tongue sensitivity, loop bending is less preferred for space closure in lingual orthodontics compared to sliding mechanics based on slightly smaller archwires. The orthodontic tooth movement associated with sliding mechanics is accomplished by repeated tipping (inclination) of the tooth rather than bodily tooth movement (parallel movement). A previous study[9] demonstrated the importance of the angle obtained by tipping tooth movement during the first contact between the edge of the bracket slot and archwire; this critical contact angle changes during sliding tooth movement. The critical angle has considerable influence on frictional forces, and increasing the critical angle causes bracket/archwire binding.[14,15] The slot dimensions are important for determining the critical contact angle in sliding mechanics.[14,16,17] The mesiodistal width of lingual brackets is shorter than that of labial brackets, which increases the tendency for tipping, and the orthodontic force arising from the archwire.[18,19]

Since Stolzenberg introduced the Russell Lock edgewise attachment, from which the self-ligating bracket was subsequently developed, various self-ligating brackets have been introduced in clinical orthodontics.[20,21] These brackets have the added advantage of high chairside efficiency due to the elimination of the ligation process, which improves patient comfort and cooperation and shortens the treatment time (due to reduced frictional force). Several studies have reported that self-ligating labial brackets do not appear to shorten the overall treatment duration,[21] although a

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How to cite this article: Zuñiga-Heredia EE, Muguruma T, Kawamura N, *et al*. Frictional Forces of Three Types of Lingual Appliance with Self-ligating Mechanisms. J Contemp Dent Pract 2021;22(6):605–609.

Source of support: Nil

Conflict of interest: None

previous *in vitro* investigation reported that these brackets produce lower frictional force than conventional edgewise brackets.[20] Commercially available lingual appliances have a relatively low profile and narrow bracket, which may produce different frictional forces compared to labial brackets. However, available information on the frictional properties of self-ligating lingual appliances is limited.[22] This study investigated the relationship between the morphological characteristics and frictional properties of three types of self-ligating lingual appliances. We hypothesized that frictional force would not vary according to the bracket design.

Materials and Methods

Materials

This study used three self-ligating lingual appliances (2D®; Forestadent Bernhard Förster GmbH, Pforzheim, Germany; Alias™; Ormco Corporation, Glendora, CA, USA; and Clippy L®; Tomy International, Fuchu-shi, Tokyo, Japan) (Table 1). For each self-ligating lingual appliance, we used a second premolar bracket and lingual tubes for the upper first and second molars. We also purchased full-size and non-full-size archwires (i.e., archwires with different cross-sectional dimensions; Ormco Corporation) for each appliance (2D: 0.016 × 0.022 in and 0.016 × 0.016 in; Alias: 0.018 × 0.018 in and 0.016 × 0.016 in; and Clippy L: 0.017 × 0.025 in and 0.016 × 0.022 in, respectively) (Fig. 1).

Frictional Properties Measured Using a Drawing-friction Test

The three lingual appliances (2D, Alias, and Clippy L), consisting of a self-ligating bracket (second premolar) and two tubes (first and second molars) were bonded to a testing jig made of a stainless steel plate ($n = 5$ for each lingual appliance) (Fig. 2). The first- and second-molar tubes were positioned at an angle of 0° using full-size, stainless steel straight wire. The second premolar brackets were positioned at an angle of 5° using a custom-made bracket-mounting device that can provide accurate angulation measurements.[8] All brackets and tubes were bonded with cyanoacrylate adhesive. The stainless steel jig with the lingual appliance was fixed to a custom-made friction-testing device attached to a universal testing machine (EZ Test; Shimadzu, Kyoto, Japan).[8] The archwires with two different sizes (full-size and non-full-size) were cut into 5-cm segments with a slow-speed water-cooled diamond saw (Isomet 11-1280, Buehler, Lake Bluff, Illinois, USA) for drawing-friction test ($n = 5$). The upper end of the wire segment was fixed with a grip that was attached to the load cell, and the lower end of the wire was fixed to a 150 gm weight. The drawing-friction test was then performed under dry conditions at room temperature (25°C). A cross-head speed of 10 mm/minute was applied over a distance of 5 mm. The static and kinetic frictional forces were determined from load–displacement curves for each wire/lingual appliance combination.[7] The static frictional force was the maximum force during the initial force increase, while the

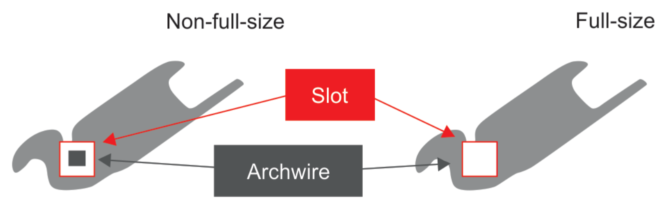

Fig. 1: Schematic cross-sectional diagram of bracket/archwire combinations

Table 1: Lingual appliances and archwires used in the present study

Lingual appliances	*Slot width*			
Cross-sectional dimension	**Nominal size*	*Measured in micro-CT*	*Non-full-size*	*Full-size*
2D, N/A[1]	3 mm	3.2 mm	0.016 × 0.016-in	0.016 × 0.022-in
Alias, 0.018 × 0.018-in	1.5 mm	1.48 mm	0.016 × 0.016-in	0.018 × 0.018-in
Clippy L, 0.018 × 0.025-in	2.2 mm	2.17 mm	0.016 × 0.022-in	0.017 × 0.025-in

[1]Not applicable due to the absence of a square slot in bracket base; *Nominal width obtained from manufacturer's datasheet

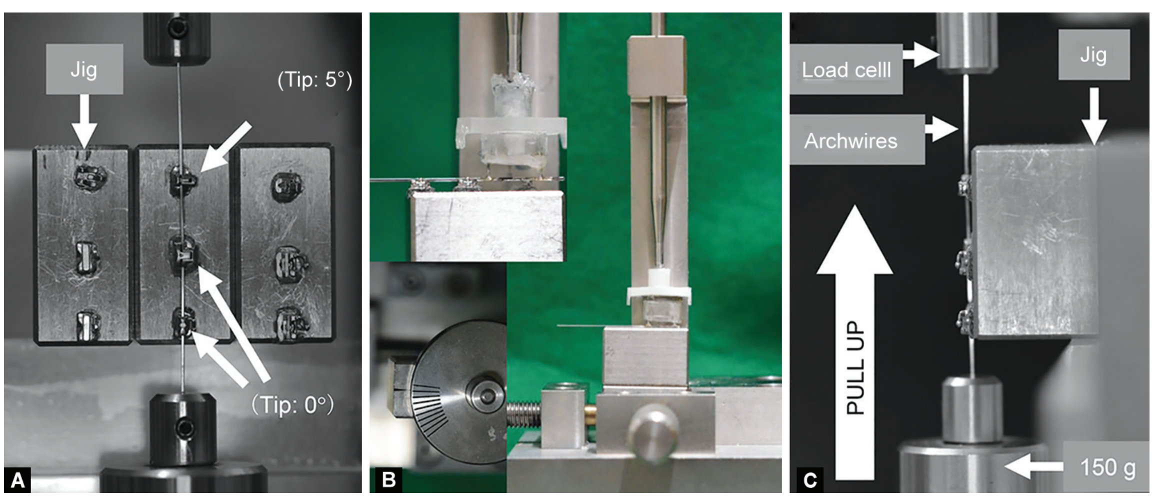

Fig. 2A to C: Friction testing system: (A) Stainless steel plate with bracket and tubes; (B) Bracket-mounting device; (C) Custom-made friction-testing device attached to a universal testing machine kinetic frictional force was the average force from the static friction point to the end of the load–displacement curve. The sample size for each lingual appliance/wire combination was 5 (the total number of appliance/wire combinations was 30).

Three-dimensional High-resolution Micro-CT Analysis

Each second premolar bracket with an attached archwire was scanned at room temperature using an inspeXio SMX-225CT system (Shimadzu) with a voxel size of 7 µm. The bracket specimens were fixed on the stage with dental wax. The system settings were as follows: 70 kV, current of 160 µA, and 125 ms integration time. The obtained three-dimensional images were analyzed using TRI/3D-BONE software (Ratoc System Engineering, Tokyo, Japan).

Statistical Analysis

Statistical analysis was performed with SPSS (version 25.0 for Mac; IBM Corp., Armonk, New York, USA). The mean values of each bracket/wire combination were examined by nonparametric Kruskal–Wallis test, and statistical significance was further determined by the Mann–Whitney U tests. A p-value <0.05 indicated statistical significance.

Results

Figure 3 shows three-dimensional images of each bracket sample. The bracket width was taken as the outer wing width of each bracket (2D: 3.20 mm; Alias: 1.48 mm; and Clippy L: 2.17 mm). Representative cross-sectional images of the 2D/non-full-size and full-size wire combinations revealed less contact between the wire and bracket slot than in the other two brackets/wires combinations, including the active clip of the Clippy L.

The static and kinetic frictional forces are shown in Figure 4 (non-full-size vs full-size archwires) and Figure 5 (for the three different lingual appliances). For all lingual appliances, the static and kinetic frictional forces were significantly higher for the full-size bracket/archwire combinations than that for the non-full-size archwire. Static and kinetic frictional forces were significantly higher for the Clippy L than for the other appliances, for both archwires. The Alias had significantly higher static and kinetic frictional forces than the 2D for both archwires, but significantly lower force than the Clippy L.

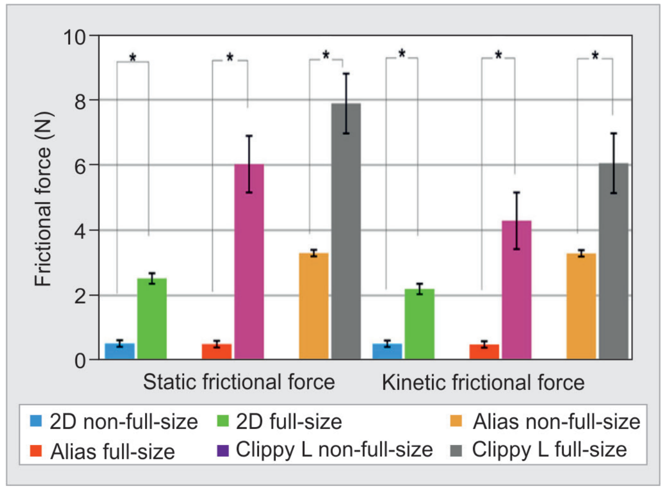

Fig. 4: Static and kinetic frictional forces for different lingual appliances with non-full-size and full-size wires. *p <0.05, Mann–Whitney U-test

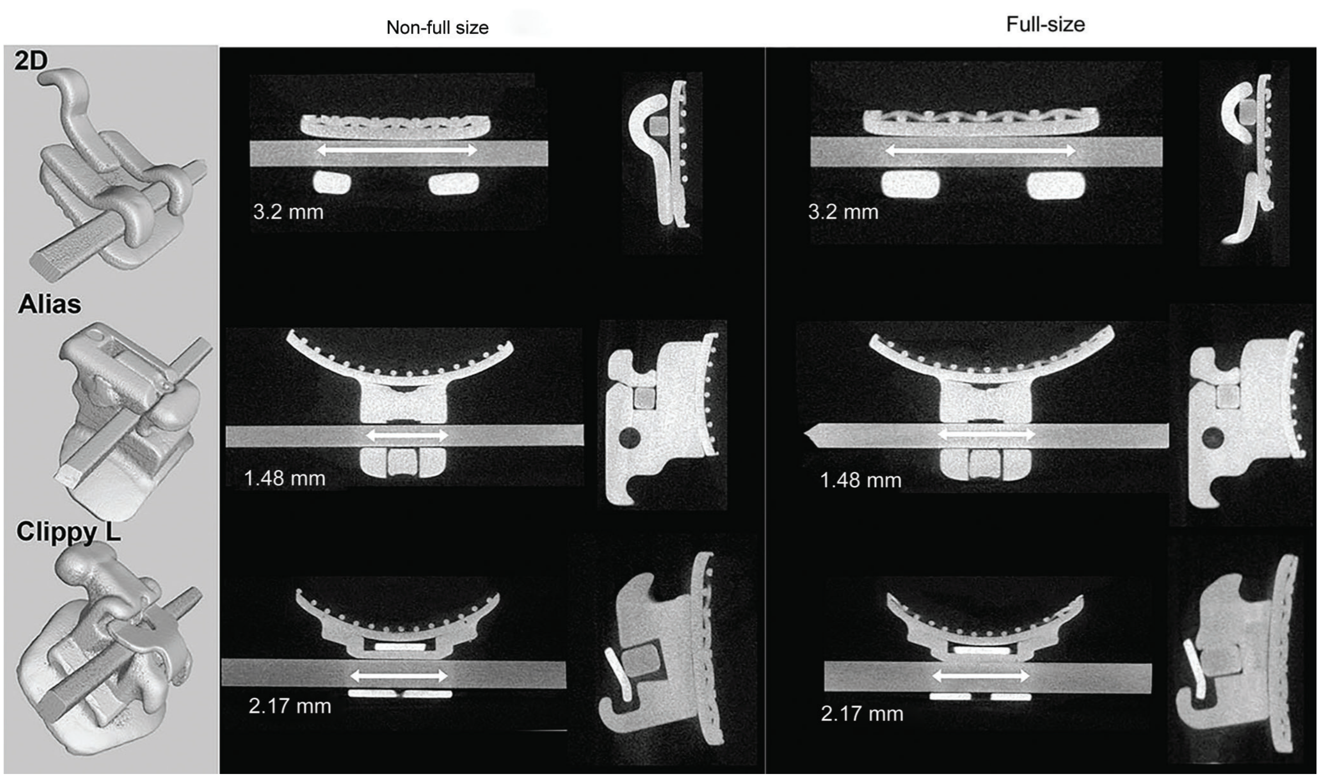

Fig. 3: Three-dimensional micro-CT images of each bracket/wire combination

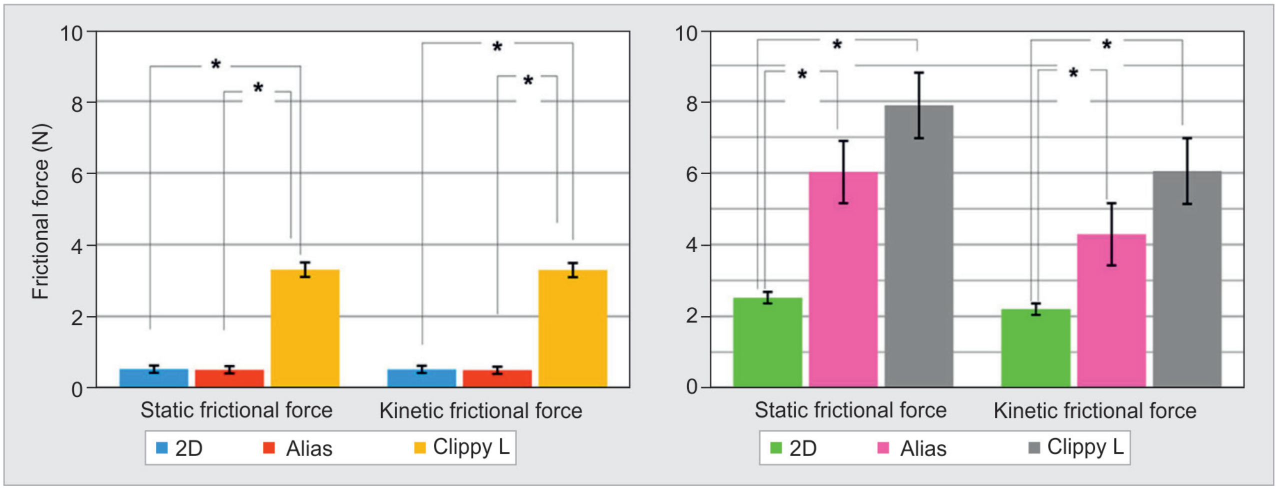

Fig. 5: Static and kinetic frictional forces for the different lingual appliances. *$p < 0.05$, Mann–Whitney *U* test

Discussion

The frictional force between the bracket and archwire during orthodontic tooth movement is an important factor that directly influences the duration of treatment.[6–10] This study compared the frictional properties of different types of self-ligating lingual appliances and showed that the frictional forces for the bracket/archwire combinations were greatly influenced by archwire size. We tested two different archwire sizes (non-full-size and full-size) according to each manufacturer's recommendations and compared the lingual appliances. Both the static and kinetic frictional forces for the full-size archwires were significantly greater than those for the non-full-size archwires, for all lingual appliances. The non-full-size archwires for the 2D and Alias brackets had the same cross-section (0.016 × 0.016-in stainless steel archwire) and showed similar frictional resistance forces. These results are consistent with previous studies[21–23] demonstrating that frictional forces increase with increasing cross-sectional archwire size. This suggests that heavier full-size archwires with a higher elastic modulus produce greater frictional forces than non-full-size archwires, since the higher elastic modulus should cause a greater active force via bending. Additionally, each lingual appliance/non-full-size archwire combination showed less contact between the bracket slot and archwire, which we assumed resulted in less frictional force.

Previous studies have shown that frictional force is influenced by bracket design.[8,9] The inter-bracket distance of lingual brackets may be shorter than that of labial brackets due to a smaller arch perimeter.[18,19] Considering the theory of critical contact angle of Kusy and Whitley,[9] a shorter inter-bracket distance may increase the contact angle and frictional force. A previous study reported that increasing bracket width increased frictional force.[24] This seems to suggest a narrower design may be advantageous for lingual brackets; however, the present study found that the 2D bracket, which had a wider outer wing (3.2 mm), produced less frictional force than the other appliances. One possible reason for this is that the 2D bracket has a unique mechanism designed to hold the archwire with two clips, instead of using a square slot with edges. Conversely, the Alias bracket, which had a narrower wing (1.48 mm), had significantly lower frictional forces than the Clippy L bracket (2.17 mm wings). Some studies have suggested that bracket width is proportional to the frictional force,[24] which may explain this difference.

Self-ligating brackets are generally divided into two types: passive and active.[25] Active self-ligating brackets have a sliding clip, which encroaches on the slot and produces an active force on the archwires. By contrast, passive self-ligating brackets typically have a slide that opens and closes vertically, thereby creating a passive labial surface at the slot. Previous *in vitro* studies[20,26] have reported that passive self-ligating brackets exhibit lower frictional force than active self-ligating ones. Similarly, the present study showed that the passive self-ligating brackets (2D and Alias) had less friction than the active self-ligating bracket (Clippy L). The wire-binding effect of active self-ligating brackets may be greater than that of passive self-ligating brackets, since the spring clip of an active self-ligating bracket encroaches on the slot, facilitating contact between the slot and edge of the wire and enhancing the binding effect.[21] Accordingly, the hypothesis that bracket design does not affect frictional force was rejected.

A previous study[9] reported the importance of the angle between the bracket and archwire for frictional force.[14,15] Orthodontic tooth movement in sliding mechanics is never linear; rather than bodily tooth movement, it is accomplished by repeated tipping (rotating) tooth movement. The tipping tooth movement in sliding mechanics influences the critical angle (bracket/archwire angle) and leads to archwire deformation, which gives rise to an active frictional force due to binding phenomena. Therefore, the bracket/archwire setup is crucial when designing *in vitro* drawing-friction tests. Previous studies reported theoretical critical angles of commercial brackets/archwires of 2–3°,[14,18] while a similar study using a drawing-friction test used an angle of 0 to 5°. This study used a critical angle of 5° to represent a clinical situation. Although it is difficult to compare our results with previous studies due to differences in experimental conditions, this study provides new insight into the frictional properties of self-ligating lingual appliances.

Summary and Conclusion

- Frictional force was significantly higher for heavier full-size than non-full-size archwire/appliance combinations.
- The 2D bracket, which had a wider outer wing, was characterized by less contact between the bracket and archwire than the Alias and Clippy L; it also produced lower frictional forces due to its archwire-holding mechanism.

- The Clippy L, which had an active self-ligating mechanism, showed higher frictional forces than the other appliances.
- The Alias, which had a narrow outer wing, had significantly lower frictional forces than the Clippy L, which had a wider outer wing.

Clinical Significance

The frictional force of self-ligating lingual appliances affects the elastic modulus of the archwire and appliance design, including the outer wing width and self-ligating mechanism.

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