Chapter 4
Binding Friction of NiTi Archwires at Different Size and Shape in 3-Bracket Bending Configuration

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Abstract During orthodontic treatment, the force released by the bent of a NiTi archwire is influenced by the friction developed in the bracket system. This in vitro study investigated the amount of friction encountered by the NiTi archwire in a 3-brackets configuration. Five different sizes within two shapes of NiTi archwire were considered for the bending test at different deflection magnitudes of 2, 3 and 4 mm. The binding friction was measured by comparing the force-deflection curve of the NiTi archwire with the use of polytetrafluoroethylene (Teflon) bracket and stainless steel brackets. The force result from the Teflon bracket was considered as a control test, utilizing its frictionless character. This investigation revealed that the binding friction is affected by the archwire size and shape. The NiTi archwire experienced higher binding friction during activation and slightly lower during the wire recovery at deactivation. The magnitude of the binding friction gradually increased with the increase of the archwire size and shape, with the largest binding friction of 7.6 N recorded from the 0.457 mm × 0.635 mm rectangular archwire and the smallest binding friction was recorded from the 0.356 mm round archwire.

Keywords Binding friction · 3-brackets bending test · Teflon bracket · NiTi archwire · Orthodontic leveling treatment

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4.1 Introduction

In orthodontic leveling treatment, a tooth is protruded to align with adjacent teeth by inducing a force onto the subjected tooth. The force is generated by bending an archwire on brackets that are glued to multiple teeth. The effective force magnitude to induce tooth movement for leveling is around 1–3 N [1]. A higher force magnitude can damage the gum tissue, while a lower force magnitude does not encourage tooth movement or prolong the treatment time [2].

NiTi shape memory alloy orthodontic archwire is widely used in current practice because they provide a constant force over a huge deflection magnitude. Also, their unique superelasticity behavior allows large strain recovery of approximately 6–8% strain without permanent deformation [3, 4]. In orthodontic treatment procedure, it is the recovery force of the archwire that induces a tooth movement [3–5]. However, the contact between the archwire and bracket produces unwanted friction. This friction restrains the deflected archwire from retraction, thus tooth movement is hindered.

The friction at the contact area between the archwire and bracket can be classified into sliding and binding resistances. Sliding friction exists from the sliding motion of the archwire on the bracket and binding friction develops when the archwire is bent at the tip/lip of the bracket slot [5].The magnitude of sliding friction is dependent on the friction coefficient between the archwire and bracket [6]. If elastomeric ligature is used to secure the archwire on brackets, the magnitude of sliding friction may increase substantially. Binding friction is also dependent on the friction coefficient, but the magnitude increases as the bent angle decrease, or in other words, as the deflection of the archwire increases [7–9]. In this regard, binding friction is also influenced by the archwire size and shape.

In normal case practice, different sets of archwire sizes are used during treatment, depending on the displacement distance and angle of the tooth that to be treated. In most of the cases, round archwires with diameter of 0.356–0.457 mm are used and a rectangular archwire of 0.406 × 0.559 mm is used at the final stage of treatment [10–12]. Selection of archwire size and shape is guided by the deflection force of archwire provided by the manufacturers. The force is measured from a 3-point bending test, and thus, friction values are not included. The objective of this work is to measure the binding friction of orthodontic archwires in 3-bracket configuration at leveling treatment.

4.2 Materials and Method

The friction measurement was done from the force-deflection behavior of the NiTi archwire bent in 3-brackets configuration. The bending jig is illustrated in Fig. 4.1a. The middle indenter resembles the subjected tooth to be moved in leveling treatment, and the two columns at each side resemble the teeth for anchoring the archwire. The

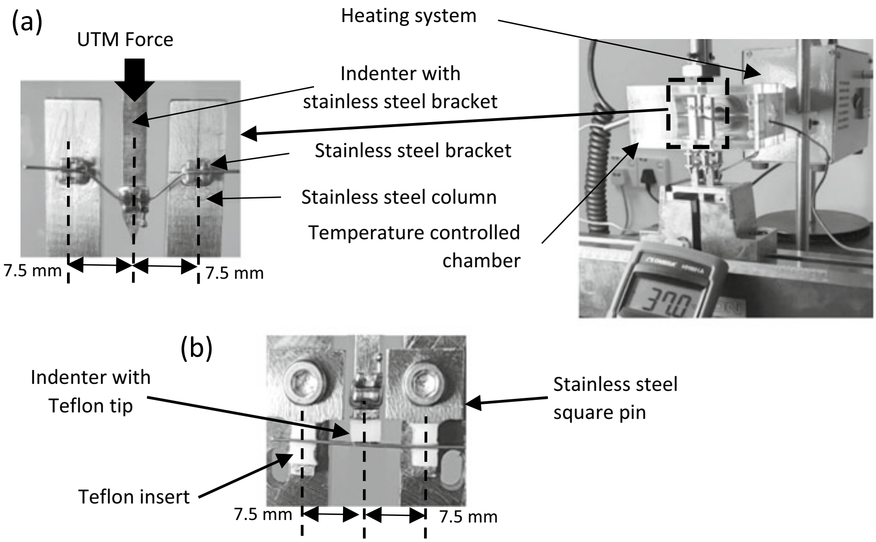

Fig. 4.1 Experimental setup of friction measurement

commercial NiTi archwires (G&H Orthodontics) were used together with a commercial stainless steel bracket, mini MBT prescription (Natural Orthodontics) with 0.559 mm slot height. The brackets were glued to the stainless steel columns by using cyanoacrylate adhesive (Supa Glue, Selleys). In this test, ligature was not used for eliminating the potential friction it might contribute. The indenter was mounted onto the load cell of the universal tensile machine (Instron 3367) to provide force to deflect the archwire. The force resolution of this tensile machine is 0.01 N. The bending span was 15 mm to resemble a common adult Asian tooth pitch at dentition. The bending test was done in a temperature-controlled chamber set at the oral temperature of 37 °C. The chamber was able to maintain the temperature at ± 1 °C accuracy.

Teflon brackets were used to demonstrate frictionless behavior during the bending test. The Teflon brackets were fabricated by cutting a Teflon bar into a small insert, then press-fitted into the slot of a stainless steel square pin, as shown in Fig. 4.1b. Teflon bracket was bolted to the stainless steel column. During the bending test, the indenter with Teflon tip is providing the force to bend archwire. The width of the Teflon pin is the same as the stainless steel bracket width, to standardize the contact surface during bending.

Bending of the archwire was done at crosshead speed of 1 mm per minute in universal tensile machine. The archwires were deflected to three different distances of 2, 3 and 4 mm at each test. Five commercial NiTi archwires were used in this bending tests. Table 4.1 shows the archwire size and shape used at different brackets types.

Table 4.1 Brackets type and NiTi archwire used

Bracket	NiTi archwire size (mm)	
	Round	Rectangular
Teflon	0.356, 0.406, 0.457	0.406 × 0.559, 0.457 × 0.635
Stainless steel	0.356, 0.406, 0.457	0.406 × 0.559, 0.457 × 0.635

During the bending test, the activation phase is when the indenter is moving downward to bend the archwire to the required deflection distance. The deactivation phase is the archwire recovery to its original position, thus the force measured by the load cell is the recovery force produced by the archwire. The activation phase resembles the installation of the archwire by the orthodontist, while the deactivation phase resembles the effective force produced by the bent archwire on its way to recovery, thus induces tooth movement.

4.3 Results and Discussion

Figure 4.2a shows the force-deflection curve of the 0.406 mm round NiTi archwire at 4 mm deflection with the use of stainless steel and Teflon brackets. In general, the NiTi archwire behaved differently with respect to the material type of the bracket. It is seen that in the presence of the stainless steel bracket, the NiTi archwire exhibited the activation and deactivation force over a gradient curve. The archwire deformation initiated with a linear elastic behavior for the first 1 mm deflection. The deflection behavior exhibited a gradient force curve when the archwire was further bent to 4 mm deflection. This implies a non-constant force of stress-induced martensitic phase transformation (SIMT) of the NiTi shape memory alloy. This gradient force trend indicates the increase of friction magnitude at the archwire-bracket surfaces as the deflection increases. On the other hand, the recovery of the archwire during the deactivation cycle initiated at a lower force magnitude. This implies that the friction encountered by the archwire while sliding in the bracket slot has reduced the deactivation force strength, thus delays the reverse phase transformation to a lower force level. As the deactivation cycle continued, the archwire force gradually increased in relation to the decreasing of friction.

On the other hand, the archwire exhibited a constant bending force in a plateau trend whenever the Teflon bracket was considered. This signifies the ability of the NiTi archwire to exert force in a constant manner in a frictionless bracket system.

Referring to Fig. 4.2a, the force slopes of the stainless steel curve and Teflon curve in the elastic region are different due to the bracket geometry. The size of the Teflon bracket is slightly different as compared to the stainless steel bracket. This happened due to machining variation in the fabrication of the Teflon bracket. Any difference in bracket width affects the bending span. The Teflon bracket with a slightly bigger bending span has produced a lower force slope as compared to the stainless steel

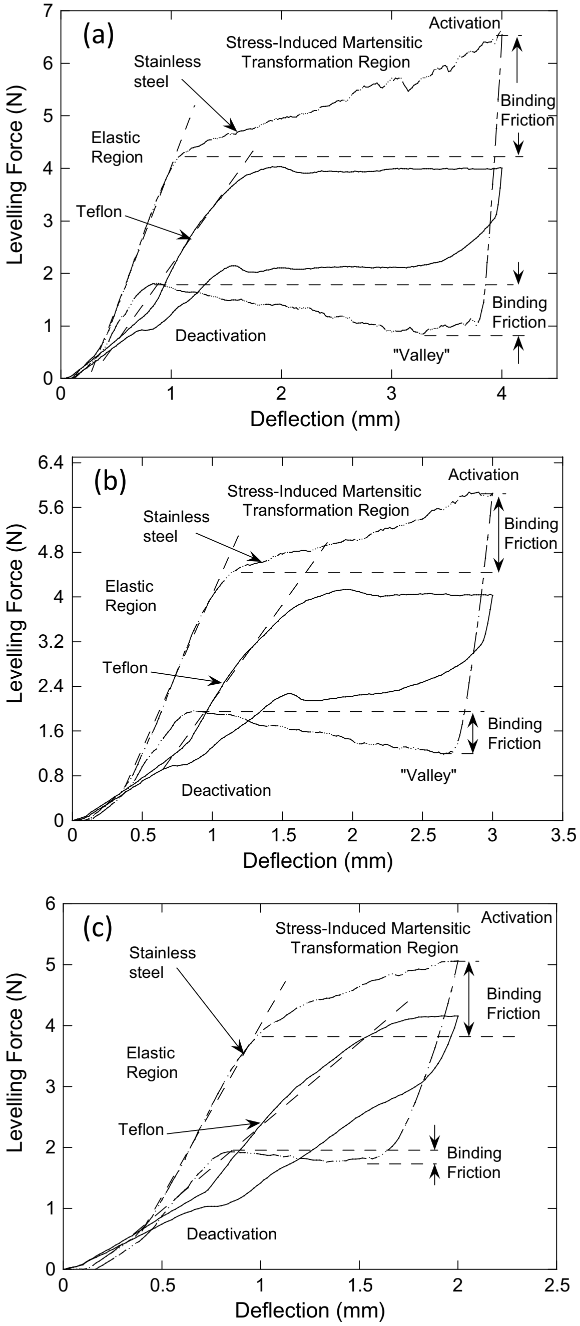

Fig. 4.2 Force-deflection curve of 0.406 mm NiTi archwire on stainless steel bracket and Teflon bracket; **a** 4 mm deflection, **b** 3 mm deflection, **c** 2 mm deflection

bracket. Teflon is relatively soft, thus small deformation happens at the bracket tip during archwire bending and this can affect the bending span.

The difference of the force magnitude at SIMT region of the force-deflection curve is considered as binding friction. Referring to the SIMT region of the force-deflection curve of stainless steel during activation, if no friction occurs, the magnitude of the force is constant along the archwire bending. This is clearly demonstrated by the flat plateau of the force-deflection curve on the Teflon bracket. The same method was done to measure the binding friction during deactivation. If no friction occurs during deactivation, the magnitude of the force is also constant along the archwire recovery. Figure 4.2a–c illustrate the force-deflection curves at 4 mm deflection, 3 mm deflection and 2 mm deflection, respectively. From these force-deflection curves, binding frictions were measured at three deflections, which refer to the magnitude of force differences at every deflection, on both activation and deactivation. The deflection of the archwire is directly influenced by the binding friction. From the force-deflection curves, binding friction during archwire activation increased from 2 mm deflection to 4 mm deflection; however, the binding friction during archwire deactivation decreased from 4 mm deflection to 2 mm deflection.

The binding frictions measured on five NiTi archwires during activation and deactivation phase at three deflections are summarized in Table 4.2. From this table, the binding friction also increases with the increases of the archwire size. Bigger archwires produced higher binding friction as compared to smaller archwires. At 4 mm deflection, during activation, 1.215 N of binding friction was measured from the 0.356 mm round archwire while 7.601 N of binding friction was measured from the 0.457 mm round archwire. During deactivation phase, the binding friction also increased as the archwire size increased, but the magnitude difference was smaller. A similar trend of binding force increment with respect to the archwire size was also observed from a rectangular archwire.

Table 4.2 shows that the archwire shape also affects the binding friction. The round archwires produced relatively lower binding frictions on both activation and deactivation phases as compared to rectangular archwires, for all deflection magnitudes. For the 4 mm deflection, the 0.406 mm round archwire produced almost 54% lower binding friction on activation as compared to the 0.406 mm × 0.559 mm

Table 4.2 Binding friction measured on five NiTi archwires at three deflections

Deflections (mm)	Loading phase	Binding friction (N) at round archwire			Binding friction (N) at rectangular archwires (mm)	
		0.356	0.406	0.457	0.406 × 0.559	0.457 × 0.635
2	Activation	0.665	0.914	1.690	2.787	3.008
3		1.102	1.680	3.178	4.355	5.499
4		1.215	2.544	3.765	5.569	7.601
2	Deactivation	0.607	0.698	1.235	1.371	2.441
3		0.776	1.223	1.668	2.052	3.371
4		0.936	1.270	1.851	2.463	4.590

rectangular archwire. While on deactivation, the friction was about 48% lower. This higher binding friction of the rectangular archwire is clearly due to its larger area moment of inertia as compared to round archwires.

The binding friction table generated in this work can help orthodontist to select the appropriate archwire size and shape for orthodontic leveling treatment. Based on binding friction results of five NiTi archwires, the 0.406 mm round archwire is more suitable because it produces small binding friction and at the same time produces sufficient magnitude of force to induce tooth movement during deactivation. Although the smaller round archwire can produce a smaller binding friction, the deactivation force produced on archwire recovery phase can be insufficient to induce the tooth movement effectively.

4.4 Conclusion

The friction measurement technique introduced in this work has successfully measured binding frictions on five different sizes and shapes of NiTi archwires in a 3-brackets bending system. The findings show that the archwire size and shape affected the binding frictions at leveling treatment. Binding frictions measured on bigger archwire size were higher than the smaller archwire size. Similarly, the rectangular archwires produced higher binding friction which was due to its bigger magnitude of area moment of inertia. Unlike sliding friction of which the magnitude is constant over the deflection range, the magnitude of the binding friction is directly proportional to the magnitude of the archwire deflection, thus the value is not constant.

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