

Load Deflection Characteristics of Nickel Titanium Initial Archwires

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Abstract

Objectives: The aim of this study was to assess and compare the characteristics of commonly used initial archwires by their load deflection graphs.

Materials and Methods: This study tested three wire designs namely copper nickel titanium (CNT), nickel titanium (NiTi), and multi-strand NiTi (MSNT) archwires engaged in passive self-ligating (PSL) brackets, active self-ligating (ASL) brackets or conventional brackets. To evaluate the mechanical characteristics of the specimens, a three-point bending test was performed. The testing machine vertically applied force on the midpoint of the wire between the central incisor and canine teeth to obtain 2 and 4mm of deflection. The force level at maximum deflection and characteristics of plateau (the average plateau load and the plateau length) were recorded. Two-way ANOVA and Tukey's test were used at P <0.05 level of significance.

Results: Force level at maximum deflection and plateau length were significantly affected by the amount of deflection. The type of archwires and brackets had significant effects on force level at maximum deflection, and plateau length. However, the bracket type had no significant effect on the average plateau force.

Conclusion: With any type of brackets in deflections of 2 and 4mm, MSNT wire exerted the lowest while NiTi wire exerted the highest force level at maximum deflection and plateau phase. The force level at maximum deflection and the plateau length increased with raising the amount of primary deflection; however the average plateau force did not change significantly.

Keywords: Orthodontic Wires; Titanium Nickelide [Supplementary Concept]

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INTRODUCTION

Success of fixed orthodontic treatments depends on the type of wire used to exert force on teeth [1]. Light continuous force is considered physiologically appropriate to move the teeth, although limited facts about optimal force are available [2]. The applied force must be beyond the biological threshold (0.5-0.7N)

but should not exceed the biological corridor (2-3N) [3]. Owing to these, the use of NiTi archwires became prevalent because of their ability to exert light continuous force and consequently improve the efficacy of treatment, particularly in aligning and leveling phase [4]. The adverse effects of friction between the wire and bracket on tooth

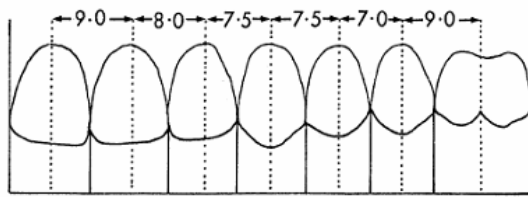


Fig. 1. inter-bracket distances (mm) on the phantom model

movement in the leveling phase have been clearly realized [4]. Schumacher et al. showed that the ligation method had the greatest effect on friction [4]. Self-ligating brackets are ligature-less and in these brackets mechanical components close the edgewise slot [5]. These brackets are categorized into ASL brackets such as In-ovation (GAC International, Bohemia, NY, USA) in which the wire is pressed by a spring clip into the edgewise slot, and PSL brackets such as Damon SL (OrmCo SDS, Glendora, USA) in which wire is not forced into the slot. Today, the most acceptable method of assessing the super elasticity of orthodontic archwires is the three-point bending test [6]. This test evaluates the load/deflection property of wire, which is known as the most important parameter in determining the biological nature of tooth movement [7]. The load deflection diagram includes loading (upper) and unloading (lower) curves. The loading curve represents the force required for engaging the wire in the bracket; whereas the unloading curve represents the amount of force delivered to the teeth by wire. Vertical distance between the two curves is related to combined hysteresis of materials and the friction between the wire and bracket. This diagram is characterized by a flat slope at the unloading curve, known as the plateau, which indicates that the delivered force is relatively constant in the range of tooth movement [8]. In general, the length of the plateau is used to indicate extension of the displacement range in which the force may be considered

approximately constant [8]. Most of the studies evaluating the properties of archwires have focused on the amount of force generated from wires at certain amounts of deflection [2,9,10]. Our study, in contrast, aimed to evaluate the load deflection characteristics, while the wires were engaged on a model similar to dental arch. The aim of the present study was to assess the maximum generated force by wires and also the characteristics of the plateau in the unloading phase, which were described using two parameters: the average plateau load and the plateau length. Furthermore, this analysis was focused on three types of archwires typically employed during the first phase of orthodontic treatment.

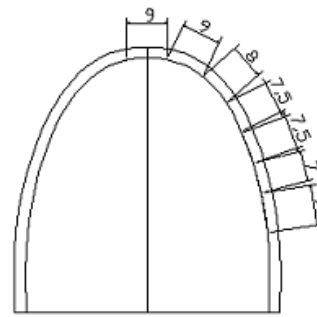


Fig. 2. Location of the teeth on the arch form based on the afore-mentioned distances and set with precise angulations

MATERIALS AND METHODS

Mechanical characteristics of three types of orthodontic 0.016-inch wires engaged in three types of brackets were evaluated using three-point bending test. The wires were CNT (Ormco, Glendora, CA, USA), NiTi (Dentaurum, Ispringen, Germany), and MSNT (SPEED Super Cable, Strite Industries, Cambridge, Ontario, Canada) and the brackets were PSL (Damon SL II, Ormco SDS, Glendora, USA), ASL (In-Ovation, GAC International, Bohemia, NY) and conventional Victory-MBTTM brackets, (MBT), (3M Unitek, CA, USA).

Model Design:

This step was performed to design and fabricate

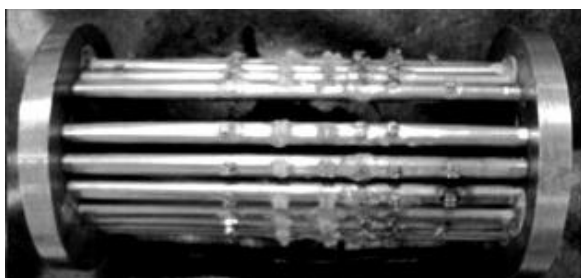


Fig. 3. The phantom model.

a model similar to human dental arch. On this model we were able to do full banding and bonding to measure the magnitude of the exerted force to misaligned teeth. The ortho small maxillary arch form template (Ormco, CA, USA) was used. The typical distances between a man's permanent maxillary teeth, suggested by Wilkinson et al, were considered in this model [10]. Figure 1 shows inter-bracket distances (mm) used on the phantom model (Fig. 1). The exact location of the teeth was determined by auto CAD software (Fig. 2). To fabricate the designed phantom model, first two discs with a diameter of 80 mm were made of stainless steel and then 11 stainless steel bars with a diameter of 5 mm and a height of 200 mm (each one representing a tooth) were welded between the two discs on specific spots, but the upper right lateral bar was not welded. Then five sets of brackets with appropriate molar tubes (0.22×0.28 inches) were stuck on the model in a manner that no slot misalignment was observed and a full size stainless steel arch wire was easily placed in the slots. Laser welding was done to strengthen the bracket-model connections (Fig. 3).

The location of maxillary right lateral incisor was left empty to simulate two severities (2mm and 4mm) of buccal malposition. The distance between the midpoints of the central and canine brackets according to Wilkinson's standards was 15.5mm [10]. The wires were placed and maintained in the conventional brackets using

elastomeric ligature (elastomeric o-modules Sani-Ties Silver, GAC Dentsply International, PA, USA) and in the self-ligating brackets using the ligating clip. Then, the models were fixed in proper relation to the bending jig of the three-point bending test machine (STM-20, Santam, Tehran, Iran). All the tests were performed in a water bath at a constant temperature of 35.5°C.

Bending Method:

The three-point bending test was conducted in buccolingual plane similar to first-order wire deflection in a universal bending machine. In this test, force was exerted vertically, on the midpoint of the wire between the central incisor and canine teeth at a crosshead speed of 1mm/min for 2mm deflection through a rod mounted on the moving head of the machine. Unloading phase was at the same speed. Loading and unloading amounts of forces were recorded. The same test procedure was performed for the more severe form of malocclusion (4 mm wire deflection). Each combination of bracket/ wire/ deflection was tested for five times with a new wire in each time (Fig. 4).



Fig. 4. Three-point bending test of the mounted arch wire kept in a water bath at a constant temperature of 35.5°C

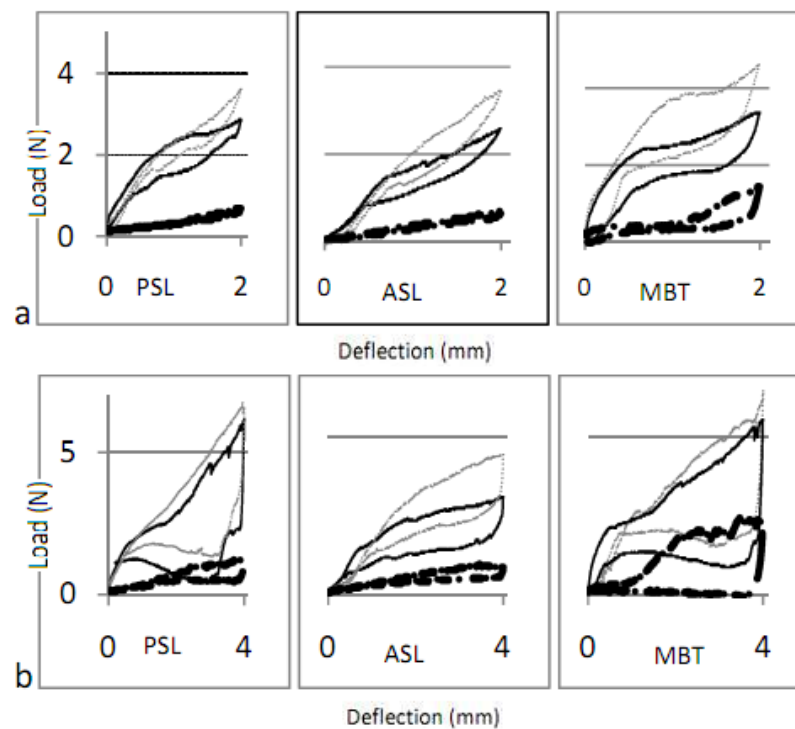


Fig. 5. The mean ($n=5$) load versus the deflection curve for the three types of wires at 2mm (a) and 4mm (b) deflection. — NiTi : Nickel titanium wire; - - - CNT : Copper NiTi wire; . . . MSNT : Multistrand NiTi wire. PSL: Passive self-ligating bracket; ASL: Active self-ligating bracket; MBT: Conventional bracket.

Measurements:

Following drawing the diagram of force versus displacement, the unloading force at maximum deflection and the characteristics of plateau (the average plateau load and the plateau length) were analyzed in all cases by a single examiner. Univariate ANOVA was used to identify the main effects (differences between bracket types, wire types and the amount of deflection), and the interaction effects of the variables. Post hoc Tukey's test was used to compare brackets and wires. All statistical tests were performed at $P<0.05$ level of significance.

RESULTS

Wires returned to their original position and shape following the unloading phase without any permanent deformation. The plateau phase of almost all graphs followed a gradual decreasing path which, revealed super elasticity feature of wires (Fig. 5).

In the present study, three parameters were comparatively evaluated. These included the maximum exerting force, the average plateau force and the plateau length. The mean values and standard deviations are shown in Table 1 and 2.

Effect of Deflections:

Force magnitude at maximum deflection was significantly affected by the amount of deflection ($P<0.001$). Force magnitude at the deflection of 2mm was 2.58 ± 1.29 N while it was 4.19 ± 1.96 N at 4mm (Table 1 and 2). The amount of deflection had a significant effect on the plateau length ($P<0.001$). These lengths were 1.18 ± 0.80 mm and 3.03 ± 1.1 mm at the deflections of 2 and 4mm, respectively (Table 1 and 2). The average plateau force was not significantly affected by the amount of deflection ($P=0.156$) and the values were 1.22 ± 0.65 N and 1.26 ± 0.90 N at the deflections of 2 and 4mm, respectively (Table 1 and 2).

Table 1. The mean and standard deviation of the maximum load, average plateau load and plateau length in each group at the deflection at 2mm deflection.

Bracket	Wire	Maximum load Mean± SD	Plateau length (mm) Mean± SD	Average plateau load (N) Mean± SD
PSL	CNT	2.84±0.11	1.42±0.05	1.71±0.03
	NT	3.73±0.08	0.73±0.06	2.03±0.04
	MSNT	0.71±0.04	1.52±0.04	0.25±0.05
	Total	2.42±1.44	1.22±0.64	1.33±0.88
ASL	CNT	2.50±0.10	1.25±0.05	1.39±0.05
	NiTi	3.47±0.07	0.83±0.08	1.42±0.13
	MSNT	0.68±0.04	1.48±0.03	0.32±0.04
	Total	2.21±1.25	1.18±0.56	1.04±0.68
MBT	CNT	3.34±0.04	0.99±0.04	1.52±0.07
	NiTi	4.56±0.11	1.39±0.05	2.15±0.04
	MSNT	1.37±0.11	1.03±0.03	0.26±0.05
	Total	3.09±1.36	1.13±0.57	1.31±1.21
Total	CNT	2.89±0.73	1.22±0.36	1.54±0.25
	NT	3.92±0.63	0.98±0.85	1.86±0.76
	MSNT	0.92±0.43	1.34±0.31	0.27±0.18
	Total	2.58±1.35	1.18±0.53	1.22±0.68

Table 2. The mean and standard deviation of the maximum load, average plateau load and plateau length in each group at the deflection at 4mm deflection.

Bracket	Wire	Maximum load Mean± SD	Plateau length (mm)Mean± SD	Average plateau load (N) Mean± SD
PSL	CNT	6.32±0.07	3.65±0.01	1.70±0.05
	NT	6.87±0.34	2.55±0.07	1.71±0.15
	MSNT	1.23±0.08	3.61±0.04	0.32±0.02
	Total	4.80±4.33	3.27±0.95	1.24±0.57
ASL	CNT	3.21±0.07	2.41±0.08	1.55±0.07
	NT	4.57±0.11	2.90±0.10	2.23±0.05
	MSNT	0.98±0.07	2.68±0.06	0.50±0.05
	Total	2.92±2.55	2.66±0.22	1.42±1.38
MBT	CNT	5.64±0.10	3.22±0.05	1.17±0.11
	NT	6.40±0.09	2.89±0.10	2.00±0.12
	MSNT	2.52±0.04	3.41±0.04	0.20±0.06
	Total	4.85±4.37	3.17±1.23	1.12±0.98
Total	CNT	5.05±1.23	3.09±0.64	1.47±0.43
	NT	5.94±1.56	2.78±0.43	1.98±0.24
	MSNT	1.57±0.88	3.23±0.94	0.34±0.21
	Total	4.19±3.23	3.03±0.68	1.26±0.85

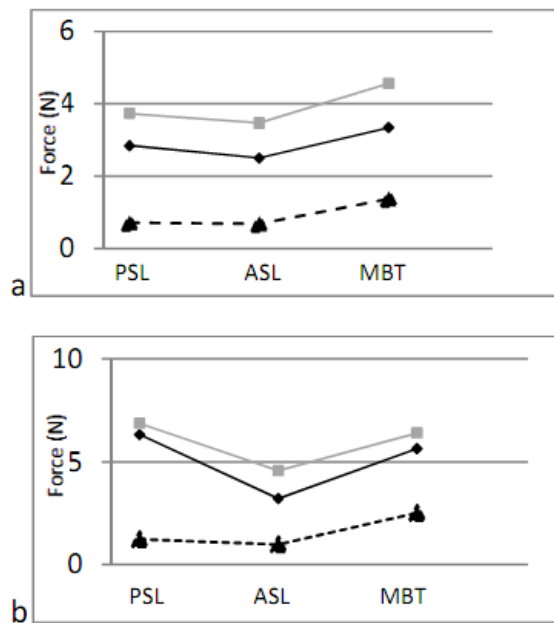


Fig. 6. The mean load versus the deflection curve for the three types of wires at 2mm (a) and 4mm (b) deflection.
 — NiTi: Nickel titanium wire; — CNT: Copper NiTi wire; - - - MSNT: Multistrand NiTi wire.
 PSL: Passive self-ligating bracket; ASL: Active self-ligating bracket; MBT: Conventional bracket.

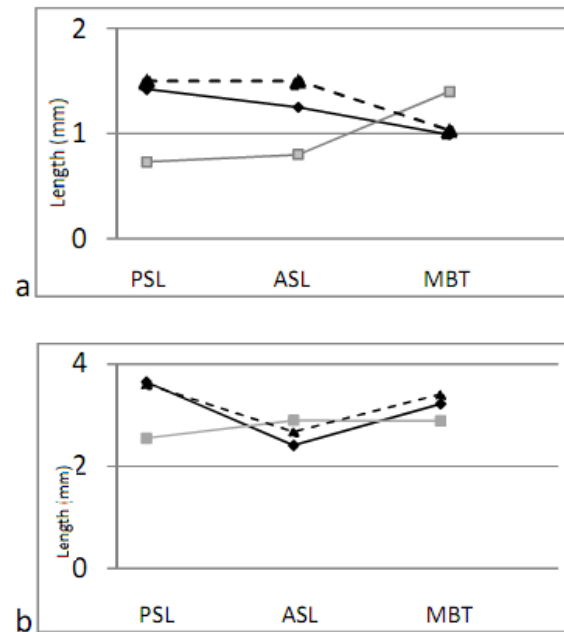


Fig. 7. Comparison of the average plateau length at 2mm (a) and 4mm (b) deflections in all experimental groups
 — NiTi: Nickel titanium wire; — CNT: Copper NiTi wire; - - - MSNT: Multistrand NiTi wire.
 PSL: Passive self-ligating bracket; ASL: Active self-ligating bracket; MBT: Conventional bracket.

Effect of Model Design:

The results of two-way ANOVA regarding the effect of combination of archwire and bracket are shown in Table 3. The effect of wire type was significant in all variables ($P < 0.0001$). The results of the Tukey's test (Table 4) indicated that at maximum deflection MSNT had the lowest force and NT wire had the highest force with significant differences ($P < 0.001$) (Fig. 6). The MSNT had the longest and NT wire had the shortest plateau lengths with significant differences ($P < 0.001$) (Fig. 7). The NT wire had the highest and MSNT had the lowest average plateau forces with significant differences ($P < 0.001$) (Fig. 8). Bracket type had significant effects on the force level at maximum deflection and plateau length ($P < 0.001$) but its effect on average plateau forces was not significant (Table 3).

The results of the Tukey's test (Table 5) indicated that at maximum deflection MBT had the highest force and ASL had the lowest force with significant differences ($P < 0.001$) (Fig. 6). Also, PSL bracket had the longest and ASL bracket had the shortest plateau lengths and the difference in this regard was statistically significant ($P < 0.001$) (Fig. 7).

DISCUSSION

The results of the present study revealed that with any type of bracket in deflections of 2 and 4mm, MSNT wire exerted the lowest while single-strand NiTi wire exerted the highest force level at maximum deflection (Fig. 6) and the plateau phase (Fig. 8). Force level at maximum deflection and plateau length increased by increasing the amount of primary deflection, but the average plateau force was

not affected significantly. The delivered force in all cases was within the range of the biological threshold and biological corridor defined by Proffit and Fields [3]. In our study, the unloading force diminished gradually in the majority of cases, but increased in some of them. This observation is thought to be related to friction and elasticity of elastomeric ligatures [11-13]. Lombardo et al, [8] also reported variable coefficients of friction between wires and brackets as the reason for this observation. Small deflections (0.5mm) of superelastic wires do not create a significant plateau phase [14]. Garrec and Jordan [15] showed that the load deflection graph of superelastic NiTi wires at a small deflection was similar to that of conventional alloys. Therefore, in cases of low dental irregularity malocclusion index, the super elasticity of this wire will not express, and the advantages of NiTi wire will not be benefited from.

In the current study, similar to the studies by Gatto et al, [16] and Lombardo et al, [8] a comparison was made between 2 and 4mm deflections. Load/deflection graph for 2mm deflection was narrow and steep while the curve of the same wire for 4mm deflection was wider with a longer plateau phase. The results showed that the super elasticity of this wire is not completely expressed at the deflection of 2mm. Higher deflection, because of more stress induced, results in more martensitic transformation; as the result, a wider range is seen between loading and unloading curves [16]. The force magnitude at maximum deflection of wires in conventional brackets (3.97 ± 1.77) was higher than that in the two self-ligating brackets because of additional force from the ligature. The force magnitude at maximum deflection in PSL brackets (3.62 ± 2.37 N) was not significantly lower than that of conventional brackets.

Table 3. Results of univariate ANOVA for each variable and their interaction

Parameter significance	P value Maximum load	P value Plateau length	P value Average plateau load
Variable			
Deflection	<0.001	<0.001	0.156
Bracket	<0.001	<0.001	0.31
Wire	<0.001	<0.001	<0.001
Deflection× bracket	<0.001	<0.001	<0.001
Deflection× wire	<0.001	<0.001	0.015
Bracket× wire	<0.001	<0.001	<0.001
Deflection× bracket× wire	<0.001	<0.001	0.013

P value < 0.05 indicates a significant result by univariate ANOVA

Table 4. Results of Post hoc Tukey's test for comparison of wires

Wire	Wire	P value for maximum load	P value for plateau length	P value for average plateau load
CNT	NiTi	<0.001	<0.001	<0.001
	MSNT	<0.001	<0.001	<0.001
NiTi	MSNT	<0.001	<0.001	<0.001

P value < 0.05 indicates a significant result by Post hoc Tukey's test

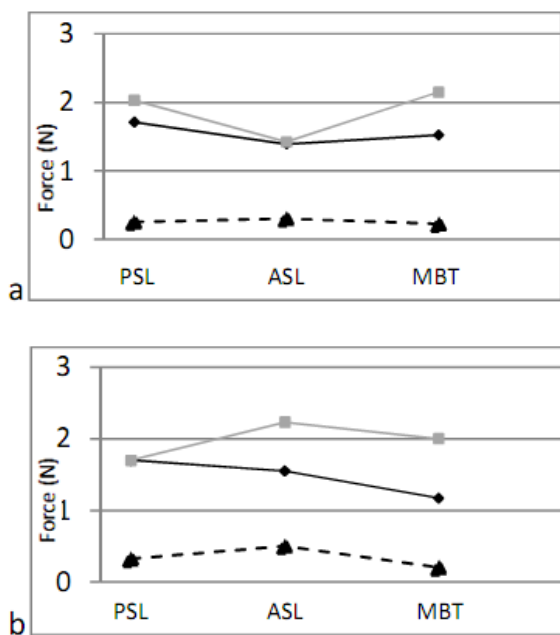


Fig. 8. Comparison of the average plateau load values at 2mm (a) and 4mm (b) deflections in all experimental groups
 ——— NiTi: Nickel titanium wire; ——— CNT: Copper NiTi wire; - - - - MSNT: Multistrand NiTi wire.
 PSL: Passive self-ligating bracket; ASL: Active self-ligating bracket; MBT: Conventional bracket.

It might be due to the sharp curves at the corners of this bracket, which exert a high reciprocal force on the wire by the rigid clip. The force magnitude at maximum deflection in ASL bracket group ($2.57 \pm 1.40N$) was the least. This finding could be related to the flexible active clip, which is able to slightly deflect with the wire.

As a result, it generates less reciprocal force in the wire. The magnitude of the unloading force affects the patients' discomfort experience.

Patients, therefore, may experience more discomfort when conventional brackets, rather than self-ligating brackets, are used. The average plateau force was lower when conventional, compared to self-ligating brackets were used in our study. This finding might be related to higher frictional force between the wires and conventional brackets. Lower frictional force between the wires and the self-ligating brackets might be the reason for higher plateau force when these brackets were used. These findings are consistent with those of Wilkinson et al, [10], Mullins et al. [17], and also Reznikov et al, [18] who stated that there is "low friction/light force versus high friction/ insufficient force". In a study by Elayyan et al, [9] loading and unloading curves showed respectively higher and lower levels of force when conventional brackets were used compared to when self-ligating brackets were applied. Although two different severities of malocclusion were compared in our study, the results showed that the amount of deflection had no significant effect on the average plateau force. Nakano et al, [19] also reported a similar result and stated that even if the amount of primary deflection of NiTi wires changes, the exerted force during unloading phase will be almost constant. Parvizi and Rock [20] in their study on three thermally activated wires obtained the same results and stated that when the amount of deflection increased from 2 to 4mm, the magnitude of unloading force did not change significantly. On the contrary, Meling and Odegaard [14] and Mallory et al. [21] concluded that the unloading stiffness of wire

Table 5. Results of post hoc Tukey's test for comparison of brackets

Bracket	Bracket	P value for maximum load	P value for plateau length	P value for average plateau load
PSL	ASL	<0.001	<0.001	0.3
	MBT	<0.001	<0.001	0.29
ASL	MBT	<0.001	<0.001	0.3

P value < 0.05 indicates a significant result by post hoc Tukey's test

is adversely influenced by the alterations in wire deflection. Moore et al. [22] observed that in 79% of a 24-hour period, the temperature of the anterior segment of the oral cavity was 33-37°C, in 20% it was lower and in only 1% the temperature was higher than this range. Although in other studies the temperature was set at 37 or 35°C [2], they concluded that 35.5°C is more suitable. We set the temperature at 35.5°C in our study. Also, in our study the wires were deflected buccally for 2 and 4 mm. Mechanical properties of wires, as shown in other studies, are not affected by altering the load direction. Wilkinson et al. [10] exerted force buccolingually in some of cases and occlusogingivally in others. Based on biomechanical demands, single-strand super elastic (NiTi, CNT) and multi-strand wires have different applications. Multi-strand wires in low friction systems are superior to single-strand superelastic wires in first phases of orthodontic treatment, because regarding the results of the current study and those of Berger et al, [23] MSNT wires, exerted one-third of the force of conventional NiTi wires with the same size; and were able to express their super elasticity at lower deflections.

These wires create full bracket engagement, which minimizes the risk of delivering excess force in primary phases of treatment of severe malocclusions, or in adults with periodontal disease. This wire consequently requires less frequent activations. Single-strand super elastic wires are recommended in straight wire system because MSNT wires cannot overcome the frictional force; the exerted force, therefore, is too small to move the tooth. Studying the graphs revealed a lower average plateau force but longer plateau length for CNT compared to NiTi wires.

Therefore, these wires are preferred in cases with severe malocclusion and/or long intervals between visits. The wires generating higher level of force and longer plateau length are indicated in derotational procedures [24].

Single-strand NiTi wires in our study showed the same character.

CONCLUSION

1-Load/deflection characteristics of wires vary depending on the bracket type and the deflection amount.

2-The MSNT and NiTi wires, combined with all types of brackets and any amount of deflection, generated the lowest and the highest average plateau forces, respectively.

3-By increasing the primary amount of deflection, the generated force by wire in the plateau phase remained constant but the plateau length significantly increased.

4-The average plateau force was greater when self-ligating brackets were used. This observation might be related to lower frictional force between this bracket and wires.

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