

***In-Vitro* evaluation of load-deflection characteristics and force levels of nickel titanium orthodontic archwires**

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ABSTRACT

Background: Nickel-titanium (NiTi) archwires have become increasingly popular because of their ability to release constant light forces, which are especially useful during initial alignment and leveling phase. The aim of the present study was to investigate and compare the load-deflection characteristics of four commercially available NiTi archwires.

Materials and methods: 200 NiTi 0.014, 0.016, 0.018, 0.016x0.022 and 0.019x0.025-inch nickel-titanium archwires from four different manufacturers (3M, Ortho Technology, Jiscop and Astar) were tested. The load-deflection properties of these archwires were evaluated by a full arch bending test in both palatal and gingival directions at 37°C temperature using a universal material testing machine. Forces generated at maximum loading of 2mm and at unloading of 1.5mm were measured.

Results: All the tested NiTi wires showed an increase in loading and unloading force with increased wire dimension. Generally, 3M gave the most flexible round wires and relatively stiff rectangular wires; with linear load deflection curves. Ortho Technology wires were flexible. Jiscop gave the stiffest round wires and the most flexible rectangular wires. Astar wires were stiff which gave the highest force levels during unloading.

Conclusion: Force levels vary greatly from brand to brand and so NiTi wire brands must be selected with consideration to their load-deflection characteristics and mechanical properties.

Key words: Load-deflection; force level; nickel titanium archwires. (J Bagh Coll Dentistry 2015; 27(3):159-164).

INTRODUCTION

Dental arch alignment and leveling is the initial stage of orthodontic treatment. Satisfactory completion of this first stage is essential if esthetic; function and stability are to be achieved ⁽¹⁾. A well-planned orthodontic treatment starts with very flexible and superelastic wires fully engaged into the bracket on each arch. Usually, the ideal archwire for that initial first stage generates a light and continuous force over a long period of time ⁽²⁾.

Super-elastic nickel-titanium (Ni-Ti) alloy wires with low stiffness and high superelasticity are generally used in the leveling and alignment stages of orthodontic treatment for efficient tooth movement and a desirable biological response ⁽³⁾. These austenitic-active Ni-Ti alloys are predominantly in the austenitic phase at room temperature.

Nickel-titanium (NiTi) alloys have been widely used in orthodontics because of their favorable mechanical properties, a remarkable feature of which is their super-elasticity ⁽⁴⁾. Super-elasticity is the transformation from austenitic to martensitic that occurs by stress application within a temperature range and is manifested by a flat or nearly flat plateau in a force-deflection curve ⁽⁵⁾.

The transition between the two phases is termed martensitic transformation, and it is responsible for the memory effect. This transformation is the result of changes in the crystal lattice of the material. Shape-memory property is the plastic deformation of NiTi wires from the martensite phase to an austenite crystal structure ⁽⁶⁾.

Most of the information about the behavior of these wires is based on mechanical laboratory testing without simulating the many variables encountered in clinical situations ⁽⁷⁾. The most appropriate wire tests those that reproduce conditions encountered clinically, with the wire constrained as part of a fixed appliance ⁽⁸⁾. Variations in model design have been shown to affect unloading deflection plots ⁽⁹⁾.

Recent studies reveal all commercial wires do not necessarily behave in the same manner. Minor differences in the production process contribute to the variation in the behavior of these wires ⁽¹⁰⁾.

This investigation details a comparison of forces achieved in different commercial NiTi superelastic wires in a deflection test of activation and deactivation that attempts to approximate clinical conditions ⁽¹¹⁾. Full arch (palatal and gingival deflection) tests for four different brands of Ni-Ti alloy wires are made under the same testing conditions to clarify their load-deflection properties.

MATERIAL AND METHODS

Five gauges of NiTi wires (0.014, 0.016, 0.018, 0.016x0.022 and 0.019x0.025 inch) were

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tested to compare their mechanical properties. The sample comprised of wires from four brands 3M Unitek (Monrovia, USA), Ortho Technology (Tampa, Florida, USA), Jiscop (Dangieahg-Dong, gunpo-si, Kyeonggi-do, Korea) and Astar (Shanghai, China).

Preformed archwire were tested with phantom head jaw (Shanghai, China) in palatal and gingival deflections with greater stability and positional accuracy. The teeth of a plastic phantom head jaw were fitted with Roth prescription 0.022×0.028 inch slot passive self-ligating brackets and buccal tubes (Ortho Technology, Tampa, Florida, USA). Secure attachment was achieved for both by bonding the base of them to the crown. Accurate slot alignment was achieved by using a plain 0.021×0.025 stainless steel arch

wire as a former while the bonding was light cured

The load site simulated a misaligned upper right canine with 15mm between the midpoints of the brackets. This interbracket distance was derived from typical tooth dimensions⁽⁸⁾. The bending test was carried out with Universal Material Tester by deflecting the wire at the midpoint. Each bending test was done 10 times, with a new piece of wire for each repetition. All tests were carried out in a water bath at temperature $37^{\circ}\text{C} \pm 0.5^{\circ}\text{C}$ with digital thermometer control (Fig.1).

Load at maximum deflection of 2mm was registered as a measure of flexibility. Load during unloading phase at 1.5mm deflection was registered as a measure of elasticity (Fig.2).⁽¹²⁾

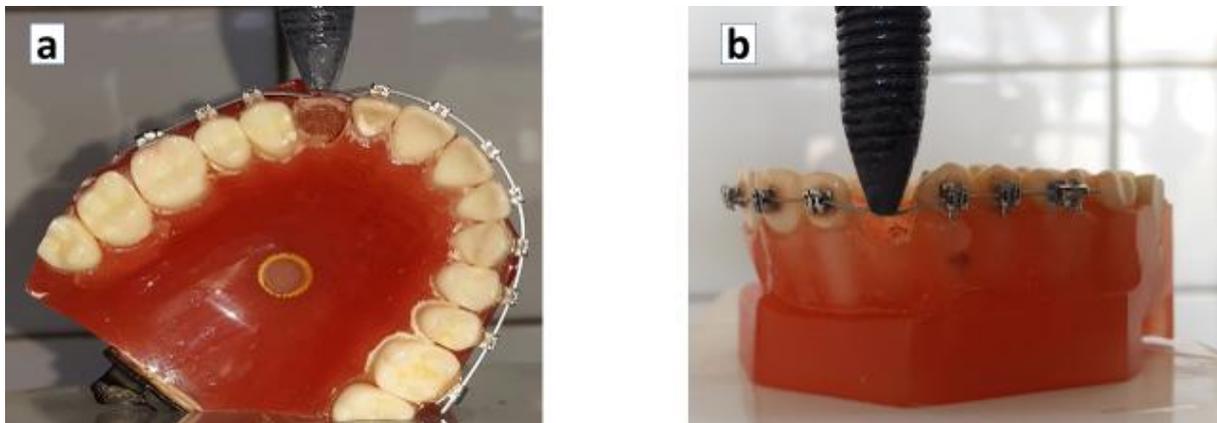


Figure 1: A test in progress on the phantom head jaw in a. Palatal b. Gingival deflection test.

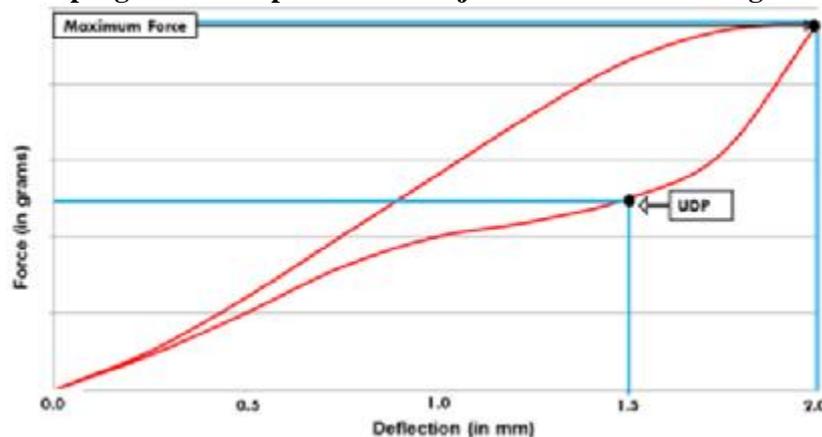


Figure 2. Typical X-Y plot of load deflection curve for NiTi wire at 2 mm load-deflection test Whereas UDP, unloading deflection point at 1.5mm.

RESULTS

Most, but not all, load-deflection graphs of both palatal and gingival tested NiTi wires confirmed features of superelasticity, with plateau regions varying in gradient and load value depending on the testing direction, wire dimension and wire brands (Fig.3).

After reach the maximum force at 2mm deflection, the unloading plot for all bending tests typically dropped very rapidly followed by a plateau region during which a relatively constant force was produced. In this superelastic range, the load curves for loading and unloading were consistent with the definition of hysteresis⁽¹³⁾.

The results of the ANOVA and LSD show that the forces generated by the four brands of the five NiTi wire gauges at loading and unloading showed highly significant difference at the $p < 0.001$ level.

Figures 4 and 5 showed the force at maximum loading of 2mm and unloading at 1.5 mm deflection using both palatal and gingival deflection tests for the five NiTi wires gauges from four brands. From these figures the following can be noted:

1. All the tested NiTi wires showed an increase in loading and unloading force levels with increase of wire dimension. The differences of force level were small in round cross section wires, but were noticeably large in rectangular cross section wires
2. In general, for all round (0.014, 0.016 and 0.018 inch) wires, both Astar and Jiscop displayed high loading and unloading forces while 3M gave the lowest forces. Whereas for both rectangular (0.016x0.22 and 0.019x0.025-inch) wires, Astar and 3M displayed high loading and unloading forces while Jiscop gave the lowest forces. Ortho Technology wire's force levels were intermediate mostly in both tests.

DISCUSSION

The factors that determine the mechanical properties of Ni-Ti alloy wires include composition, heat treatment, and degree of working. Concerning the composition ratio of nickel and titanium, most manufacturers are cautious about releasing such information, as it is regarded as a trade secret⁽¹⁴⁾. This study agreed with Nakano et al.⁽¹⁵⁾ who observed great variations in force values with different NiTi wires of the same diameter, indicating that the wires are intrinsically different and therefore should be differentiated according to their characteristics.

Loading curve represents the force required to insert the wire in the bracket on the crowded teeth, therefore, the force is usually measured at the last deflection of loading curve (maximum force level). The wires with highest maximum force were stiffer, while the wires with lowest force were flexible⁽¹⁶⁾. The differences of forces may be due to that the martensitic transformation (SIM) occurred earlier for the lowest force wires than for the highest force wires⁽¹⁴⁾.

For round wires, 3M Ni-Ti wires exerted the least maximum loading force which agrees with the findings of Gatto et al.⁽¹⁰⁾ who also found their load-deflection curves to be narrow and steep at 2mm deflection but were wider with

larger plateau at 4mm deflection. This means that at 2mm these wires did not express their superelasticity as greater deformation generate the martensitic transformation induced by this stress (SIM). On the other hand, 3M 0.019x0.025 inch wires showed the highest maximum loading force which may be due to that some austenitic NiTi wires exhibit stiffness higher than that of TMA wires, if the deformation does not reach that of the proportional limit⁽¹⁷⁾.

The unloading curve represents the force delivered to teeth during treatment and usually is measured in several deflection points. However, the different brands of Ni-Ti alloy wires tested varied widely in the force levels they exerted. The level of susceptibility of the periodontium is one of the essential factors for determining the effective and safe value of the force which should not be exceeded when applied to a single tooth⁽¹⁸⁾.

An ideal archwire should be able to deliver differential forces to the arch segments. The force should range from about 70g to 80g in the incisor area and gradually increase toward the posterior segments, up to 300g.⁽¹⁹⁾ An optimal performance of austenitic NiTi wires will be obtained in cases of severe dental crowding, when an accentuated deflection due to the irregular interbracket span will generate SIM in a localized area of the arch, usually the lower incisor area. Mild crowding does not necessarily require the use of superelastic wires, and a small diameter alloy such as 3M wire will generally perform as well⁽²⁰⁾. Our study agreed with the study of Sarul et al.⁽¹⁸⁾ during testing the mechanical properties of the NiTi wires of various diameters, they found that some round section wires release forces which fall within the range of optimal forces. That makes them more clinically useful.

Some rectangular wires as with 0.019x0.025 inch Jiscop wires, the loading force were relatively high but, after 1.5mm unloading the force were the lowest in range of 884g to 643g for both tests. This could be explained by Garrec and Jordan⁽²¹⁾ who stated that the value of stiffness appears to vary with wire size but depends on the ratio of volume of martensitic transformation i.e. a large-size rectangular wire does not produce necessarily high forces during unloading.

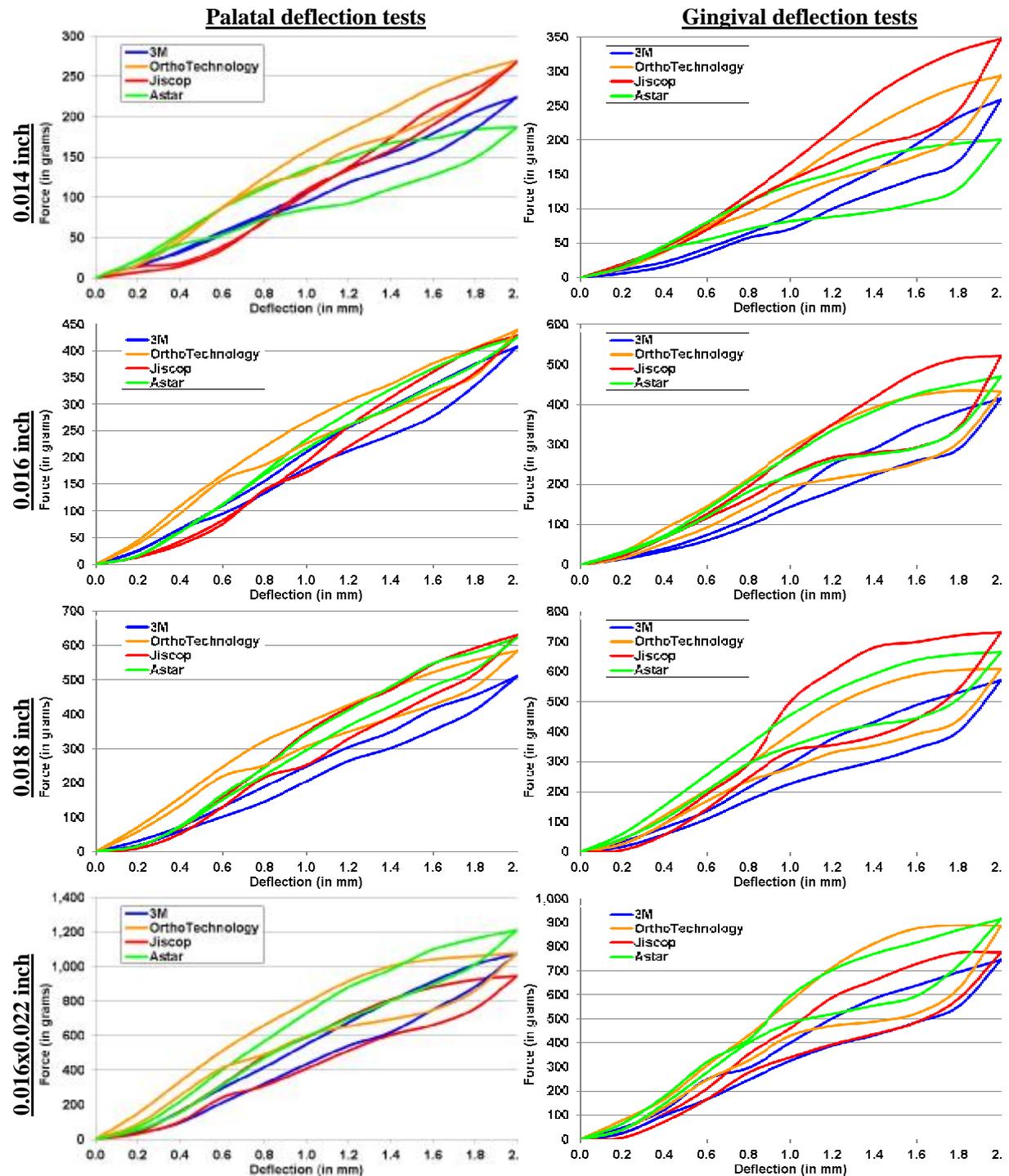
So, in this study, the archwires can be classified according to their flexibility (from highest to lowest) into 3M, Ortho Technology, Astar and Jiscop wires for both round and rectangular wires.

As conclusions;

1. All the tested NiTi wires showed an increase in loading and unloading force with increase of wire dimension.
2. In general, for round wires, Astar and Jiscop displayed high loading and unloading forces while 3M gave the lowest forces. Whereas for

rectangular wires, Astar and 3M displayed high loading and unloading forces while Jiscop gave the lowest forces. Ortho Technology wire's force levels were intermediate.

3. Wires can be classified (from highest to lowest) according to their flexibility as 3M, Ortho Technology, Astar and Jiscop.



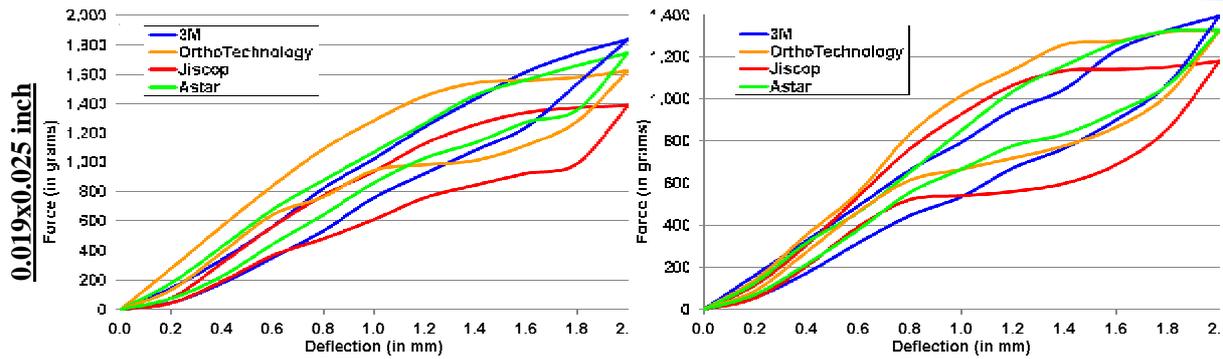


Figure 3: Load deflection curves for the 0.014, 0.016, 0.018, 0.016x0.022 and 0.019x0.025 inch wires from four brands using both palatal and gingival deflections.

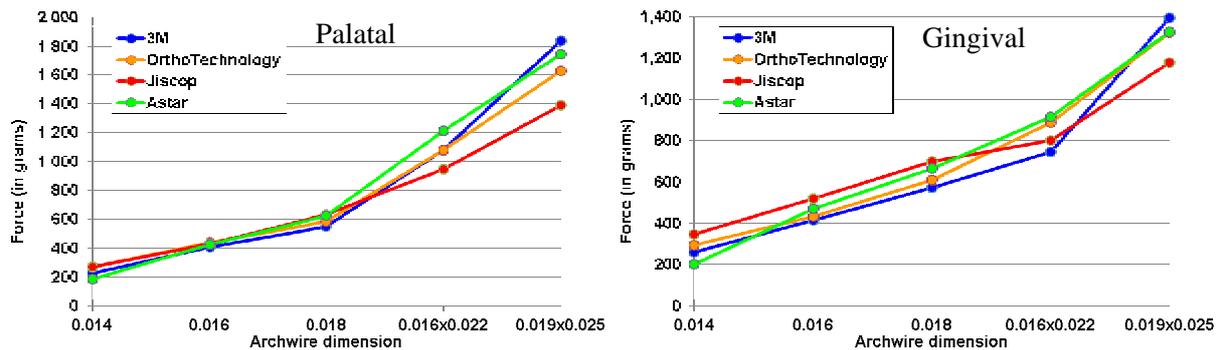


Figure 4: Maximum loading Forces at 2mm deflection for the five NiTi wires gauges from four brands using both palatal and gingival deflection tests.

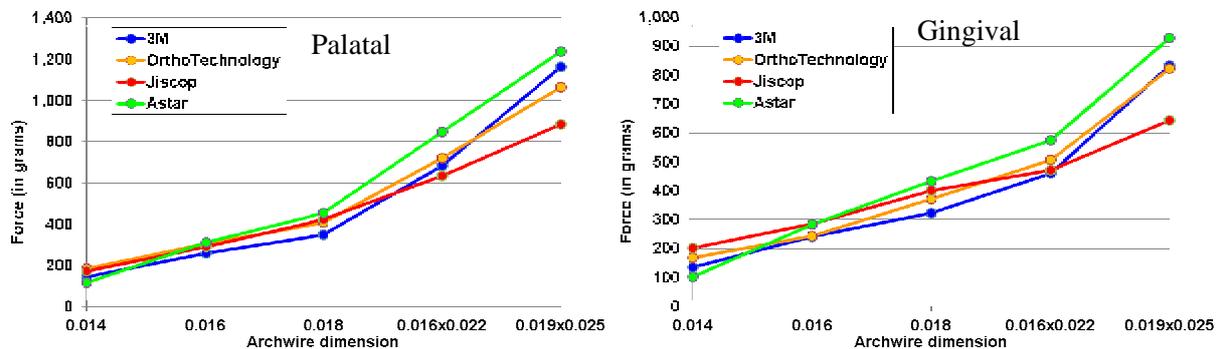


Figure 5: Unloading forces at 1.5mm deflection for the five NiTi wires gauges from four brands using both palatal and gingival deflection tests.

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