

How to Cite:

Maliael, M. T., & Babu, H. (2022). Load deflection characteristics of copper nickel titanium orthodontic Archwires. *International Journal of Health Sciences*, 6(S6), 4008–4016. <https://doi.org/10.53730/ijhs.v6nS6.11562>

Load deflection characteristics of copper nickel titanium orthodontic Archwires

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Abstract---Aim: The aim of this study was to evaluate and assess the force applied by a broad arch form orthodontic archwire on displaced teeth in ovoid arch form maxillary dentition. Materials and Methods: An in-vitro three-point test was devised to study force applied. An Ovoid form Maxillary pre-treatment model was selected at random. Right Lateral incisor and left second premolar teeth were trimmed out to simulate deflected teeth. Three different brands of wires were evaluated. The wires were divided into four groups. Each group had 10 wires for testing. The testing was done in both sites. ANOVA test was done to compare the mean force levels. Results: The lowest force level at 0mm deflection was recorded at 1.27gf and the highest force level at 4mm was recorded at 355.88gf. Conclusion: The forces applied were low and there was no significant difference in the force levels among the groups.

Keywords---load deflection, copper nickel, titanium, orthodontic.

Introduction

Correcting the alignment of teeth forms the very basis of orthodontic treatment. It is the preliminary phase in fixed orthodontic appliance therapy. It is accepted that to achieve tooth movement efficiently, effectively and by minimizing the risk of complications, it would be best to use light and continuous forces. Nickel-Titanium was introduced in the 1960s in the United States Naval Ordnance Laboratory as a structural component for torpedoes^{1,2}. The material presented unusual ductility and toughness compared to other intermetallic alloys. Further

investigations highlighted the shape memory properties of this alloy. This discovery led to its introduction into orthodontics^{3,4}.

The success of NiTi today is attributed to their super elasticity and shape memory. Super elasticity is seen on the load-deflection curve in the horizontal region during unloading which is referred to as a plateau. Kusy termed this elastic behaviour pseudoelasticity⁵. These properties are associated with the phase transitions within the alloy between the martensitic and austenitic phases that occur by either lowering the temperature or by the application stress over a certain temperature range⁶. This phase transformation occurs only if the deflection is high enough⁷⁻¹⁴. The addition of ternary components such as copper to NiTi has led to improvement in transition temperatures¹⁵. The resultant benefit is that the alloy exhibits different characteristics at the room and intraoral temperature when used for the orthodontic levelling and aligning stage. At room temperature, the archwire exhibits martensitic phase and the archwire is ductile. This helps in easy engagement into brackets thereby increasing patient comfort¹³. At the intraoral temperature, the alloy exhibits austenitic phase and the wire applies constant, light, and continuous forces as the original arch form is re-established thereby improving the efficiency of tooth movement¹⁶⁻²¹.

The Damon passive self-ligating system has introduced broad arch form wires which claims better arch development along with ultra-light forces²². Several studies have claimed a greater increase in the intermolar arch width in the Damon groups when compared to the control groups²³⁻²⁵. Both active and passive self-ligating appliances have been compared in various studies for maxillary transverse arch width changes^{26,27}. Manufacturers of both systems have claimed different advantages of their systems such as better torque control but studies have reported variations in torque expressions²⁸⁻³¹. In today's practice, the non-extraction treatment approach has been gaining popularity. This approach has been utilising broad archwires for arch expansion and development to gain space and align teeth. However, there is less evidence on the amount of force applied by these broad arch form wires in patients with an ovoid or narrower arch form. The main purpose of this study is to assess and evaluate the force applied by broad arch form Damon archwire on displaced teeth in an ovoid arch form maxillary dentition.

Materials and Methods

Study Design

An in-vitro three-point bend test was designed to evaluate the loading and unloading forces of the selected Copper Nickel Titanium (CuNiTi) wires at fixed deflections at specific regions along the arch wire.

Method

Pre-treatment digital records from the institution were screened for arch forms. Digital models of patients with ovoid arch forms were retrieved. Among 100 digital study models, one model was randomly chosen for the study. The digital model was exported as a Standard Tessellation Language (.stl) file to the 3-Shape Ortho-

Analyser software (3Shape Global, Copenhagen, Denmark) to verify the arch form. The digital file was then sent for 3D printing. The model was printed using a 3D printer (SprintRay Pro 95 3D Printer, SprintRay Inc, California, USA) using a Die and Model resin (SprintRay Die and Model 2 Gray, SprintRay Inc, California, USA). The right maxillary lateral incisor and the left first premolar were trimmed out creating a void in order to facilitate unhindered movement of the flex fixture (2kN Flex Fixture for miniature components, Instron, Illinois, USA) in a labiolingual direction. A positioning jig made up of modelling wax was constructed around the base of the model so the Flex Fixture contacts the arch wire at right angles during loading and unloading.

Brackets and Wires

Metal self-ligating brackets (Ormco Damon Q standard torque) were positioned at the FA point and then bonded using cyano-acrylic adhesive. Ten arch wires of four different types of Copper Nickel Titanium wires were used for testing (Table 1).

Table 1
Different wires used for testing in this study

Group 1	0.013in Damon Broad Arch form CuNiTi wire (Wire stops crimped mesial and distal of the left central incisor). ($N=10$)
Group 2	0.013in Damon Broad Arch form CuNiTi wire (Wire stops crimped mesial and distal of the right first premolar). ($N=10$)
Group 3	0.013in Tanzo Broad Arch form CuNiTi wire. ($N=10$)
Group 4	0.014in Ovoid Arch form CuNiTi wire. ($N=10$)

Testing

Arch wires of proper length were placed in the bracket slots and the shutters were closed. In group 1 and 2 the crimp-able stops were placed as specified in the above table and crimped. The model was later placed in the universal testing machine with the help of the wax positioner to the. The deflection was evaluated at both the lateral incisor and second premolar sites. The force-deflection was evaluated using a universal testing machine (Instron, Illinois, USA) at 0mm, 2mm, and 4mm. Once the load cell was released the unloading forces were also evaluated at the same deflections (Figure 1). The crosshead speed was set at 0.5mm/min. The measurements were recorded in gram force(gf) (Table 2).

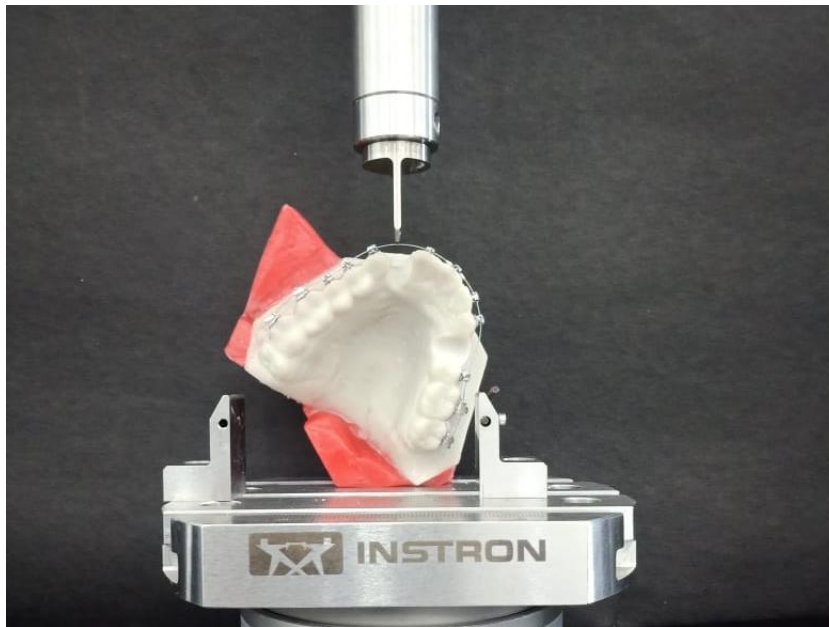


Figure 1. Modified 3-point bend test being utilised to evaluate the loading and unloading force

Table 2
Mean force values obtained from the 3-point bend test

Group s	Deflection/Unloading forces (gf)									
	At 0mm		At 2mm		At 4mm		At 2mm		At 0mm	
	LI	PM	LI	PM	LI	PM	LI	PM	LI	PM
Group 1	1.2 7	2.0 3	66.28	96.8 7	200.8 8	198.8 4	23.2 5	31.5 7	-5.50	0.71
Group 2	2.1 0	6.4 6	90.75	73.4 1	343.6 4	272.2 6	-2.03	-7.40	- 30.2 8	- 31.4 1
Group 3	8.2 0	5.7 4	109.1 0	91.7 7	298.7 7	295.0 0	60.8 1	31.5 1	- 10.1 9	- 10.1 9
Group 4	1.7 2	- 2.3 9	154.9 9	96.8 7	355.8 8	191.7 0	-9.33	- 10.9 1	- 16.5 1	- 16.5 1

Statistics

The readings were then tabulated onto a spreadsheet and statistics were done using IBM SPSS version 23. One way ANOVA test was performed to evaluate the difference among the groups.

Results

The One-way ANOVA test shows no significant difference among the groups at all deflection and unloading points evaluated. The testing showed that at null deflection before the application of the load in the lateral incisor site wire 1 exhibits the lowest force and wire 3 exhibits the highest force. At null deflection in the premolar site wire 4 exhibits the lowest force and wire 2 exhibits the highest force. At 2mm deflection in the lateral incisor site wire 1 exhibits the lowest force and wire 4 exhibits the highest force. At 2mm deflection in the premolar site wire 2 exhibits the lowest force and both wires 1 and 4 exhibit the highest force. At 4mm deflection in the lateral incisor site wire 1 exhibits the lowest force and wire 4 exhibits the highest force. On unloading, at 2mm in the lateral incisor site wire 4 exhibits the lowest force, and wire 3 exhibits the highest force. In the premolar site wire 2 exhibits the lowest force and wire 1 exhibits the highest force. On the complete removal of the load in the lateral incisor site, wire 2 exhibits the lowest force, and wire exhibits the highest force. In the premolar site, after complete removal of the load wire 2 exhibits the highest force, and wire 1 exhibits the highest force.

Discussion

Choosing appropriate arch forms for patients has been a topic of discussion for long, various opinions and studies have been put forth and conducted in this respect³²⁻³⁶. With continuous development of CuNiTi wires, broad arch form CuNiTi wires are being used in passive self-ligating brackets to promote arch development^{22,24}. Studies that have been conducted to verify the arch development capabilities of these types of appliances have shown that there is a significant dentoalveolar transverse expansion and mild increase in the labial tipping of the lower incisor³⁷⁻⁴¹. It should be taken in to account here that broad arch formed wires are deflected through substantial distances to be ligated into the brackets. Force levels need to be within orthodontic optimum for ideal physiological response to arch wires. Studies have evaluated the forced deflection recent CuNiTi wires using a three-point test showed that the force applied is lower than that of NiTi with a greater plateau and reduced load deflection^{42,43}. The study by Copelovici et al observed that, the higher the transition temperature the lower the load deflection of CuNiTi wires⁴².

Advantages such as reproducibility and ease of use, has helped the three-point bending test developed by Miura et al achieve the status of gold standard evaluate and compare flexural properties of orthodontic wires⁹. Various authors have attempted to modify the test to simulate variables encountered in clinical practice when the wire forms a part of a unit of a fixed appliance^{8,44,45}. In a previous studies conducted by Mallory et al and Wilkinson et al, a customised test was conducted to simulate clinical condition but the force applied in a occluso-

gingival direction^{12,46}. In this study, the test was modified to replicate the clinical scenario by using an ovoid arch form model. The results observed in the study show that force levels were varied 1.27gf at 0mm deflection to 355.88gf at 4mm deflection.

Efficient tooth movements require the use of light and continuous force delivery. Other in-vitro studies have shown that super elastic NiTi arch wires exhibit superior properties and efficiency in aligning than conventional NiTi alloys. Lombardo et al reported that CuNiTi shows significantly lighter forces and a longer plateau. This in turn corresponds to continuous forces when compared to the conventional NiTi of similar dimensions. These properties have led to the widespread use of CuNiTi in the clinical practice to deliver light and continuous force required for physiological tooth movement and prevent tissue hyalinization and improve patient comfort. Although the results of the in-vitro study enable the further understanding of materials used in orthodontics, it cannot reliably replicate the complex interaction of the oral environment. This is a major limitation of this study.

Conclusion

From the results obtained in testing it can be concluded that the Copper Nickel Titanium Broad arch from arch wires applies very light force on an ovoid arch. There isn't a significant difference in the force applied by the wires evaluated in this study.

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