Load Deflection Properties of Small Diameter Titanium-Niobium-Tantalum-Zirconium Archwire(An In Vitro Study)

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Abstract

Objectives: This study aimed to evaluate the load deflection properties of new niobium-based beta titanium archwire (Gummetal) in comparison with superelasticnickel titanium (SE-NiTi) and copper NiTinickel titanium (Cu-NiTi) archwires.

Methods and Material: Gummetal, superelasticNiTiand copper NiTiarchwire segments of 0.014-inch diameter were examined by three point bending test, using Instron testing machine with 10 Newton (N) load cell. Wire segments were tested at 2 and 4 mmdeflections, and at a temperature of 37±1°C. One-way analysis of variancewas used to compare the means of the groups at a significance of $p < 0.05$.

Results: At 2 mm deflection, the maximum force values and unloading forces of Gummetalwere significantly higher than those of the control (SE-NiTi and Cu-NiTi) archwires. At 4 mm deflection, there was no significant difference between the maximum force values of Gummetal and SE-NiTiarchwires, however they were significantly higher than those of Cu-NiTiarchwire. Unloading forces of Gummetalarchwire at 4 mmdeflection were initially significantly higher, then became significantly lower than the control wires at 1 mm unloading deflection point.

Conclusions: The present study showed that Gummetalarchwirewas less efficient in providing continuous forcesin comparison with SE-NiTi and Cu-NiTiarchwires.Gummetalarchwire cannot be considered superelastic, and its use in the alignment phase may better be limited to mild crowding cases.

***Key words**: Titanium-niobium-tantalum-zirconium; Gummetal;load deflection properties; three-point bending test.*

Introduction

Aligning archwires that are used at the beginning of the orthodontic treatment are intended to relieve dental crowding and rotations with light continuous forces; therefore these wires should ideally havegood springback, formability, joining ability, biocompatibility, low friction and a low cost (1,2). Nickel-titanium (NiTi) alloy wires are most commonly used during the leveling and alignment stage of orthodontic treatment owing to their superelasticity and excellent springback properties(3).Despite these advantages, NiTi wires have drawbacks, such as their poor formability, which prevents adding detailing bends to compensate for incorrect bracket positioning at the beginning of orthodontic treatment;they are also not shape-formable and may cause expansion or contraction in the canine and/or molar region when an ideal arch form is not available;in addition, they may not be suitable for patients with nickel allergy due to their high nickel content (4).

A new niobium-based beta titanium alloy wire has recently been developed. Its chemical composition in mole percentage is Ti 23, Nb 0.7, Ta 2, Zr 1.2, along with oxygen [5]. The new titanium-niobium-tantalum-zirconium (TiNbTaZr) archwire is manufactured by Rocky Mountain Morita Corporation in Japan and is marketed under the trade name Gummetal®. According to the manufacturer, the wire is nickel-free, superelastic, highly formable, has a low coefficient of friction and a high springback effect without hysteresis. These properties can make Gummetalarchwire a good alternative to NiTiarchwires in the alignment phase of orthodontic treatment when a formable and nickel-free wire is needed.Some of the mechanical properties of Gummetalarchwirewere studied, including its bending stiffness, torque moment, cyclic fatigue behaviour, and frictional forces [3, 6-8]. In addition, the effectiveness of Gummetal as initial archwire in aligning teeth was compared clinically with that of superelastic-NiTiin a double-blind randomized clinical trial, and the study showed no significant difference in performance between these two types of wires, thus it was suggested that a laboratory study would be more appropriate to determine precise differences between Gummetal and NiTiarchwires[4].

Since limited information are available in the literature regarding the load deflection behavior of TiNbTaZr (Gummetal) archwire, the aim of the present study was to evaluate the load-deflection properties of small diameter TiNbTaZr (Gummetal) archwirein comparison with superelastic-NiTi and copper-NiTiarchwires, at 2 mm and 4 mm deflections, by using three-point bending test.

Methods and Material

In this study, three different types of titanium archwires, with a diameter of 0.014-inch were tested, as shown in table 1.

Table 1 Orthodontic wires tested.

Type of the wire	Manufacturer	Dimension	code
Titanium-Niobium-Tantalum-Zirconium	JM Ortho Corporation, Tokyo, Japan	0.014-inch	TiNbTaZr (Gummetal)
Superelastic- Nickel Titanium	Dentaurum, Ispringen, Germany	0.014-inch	SE-NiTi
Copper-Nickel Titanium 27°	Ormco Corporation, Glendora, Italy	0.014-inch	Cu-NiTi

The specimens were prepared by cutting the two straight end sections from each type of wire; the sections were 30 mm in length. A custom acrylic block with two fulcrums was madefor the three-point bending test. A central incisor and a canine bracket (Dentaurum, Ispringen, Germany) with a slot size of 0.022 × 0.030 inches were bonded to the fulcrums with an inter-bracket span of 14 mm, which is equivalent to the distance between the central incisor and canine brackets [9].To eliminate the effect of tip and torque, a 21×25 stainless steel wire was ligated into the brackets before bonding them.

Because a heat-activated wire (Cu-NiTi 27°C) was used as a control in this study, all wire specimens were tested inside a digital water bath (HH-S, Zhejiang, China) that was placed at the base of the testing machine.

The acrylic block was fixed to the base of the water bath. The water inside the bath was kept at a temperature of 37±1°C. Before starting the testing procedure, each wire specimen was ligated into the brackets on the block using elastomeric ligatures and left submerged in the waterfor at least 60 seconds to achieve thermal equilibrium(10). The test was then carried out by using universal testing machine (Instron H50KT Tinius Olsen testing machine, England) with a 10 N load cell. The force was applied by chisel-edge blade attached to the moving part of the Instron machine in a vertical (occluso-gingival) direction toward the middle portion of the wire at a crosshead speed of 2 mm/min for both loading and unloading as shown in figure 1. The wire specimens were deflected by 2 and 4 mm in separate load deflection tests. The test was repeated five times for each type of wire in both deflections, thus a total of 30 wire sections were tested. Load values were gathered from the unloading (deactivation) curve, as these represent the forces that the wire exerts to move the teeth when it elastically springs back after being placed (11,12), in addition to the maximum force value. Load values were reported at 1, 2, 3 and 4 mm when the wire specimen was deflected by 4 mm, and at 1, 1.5and 2 mm when the wire specimen was deflected by 2 mm (9).

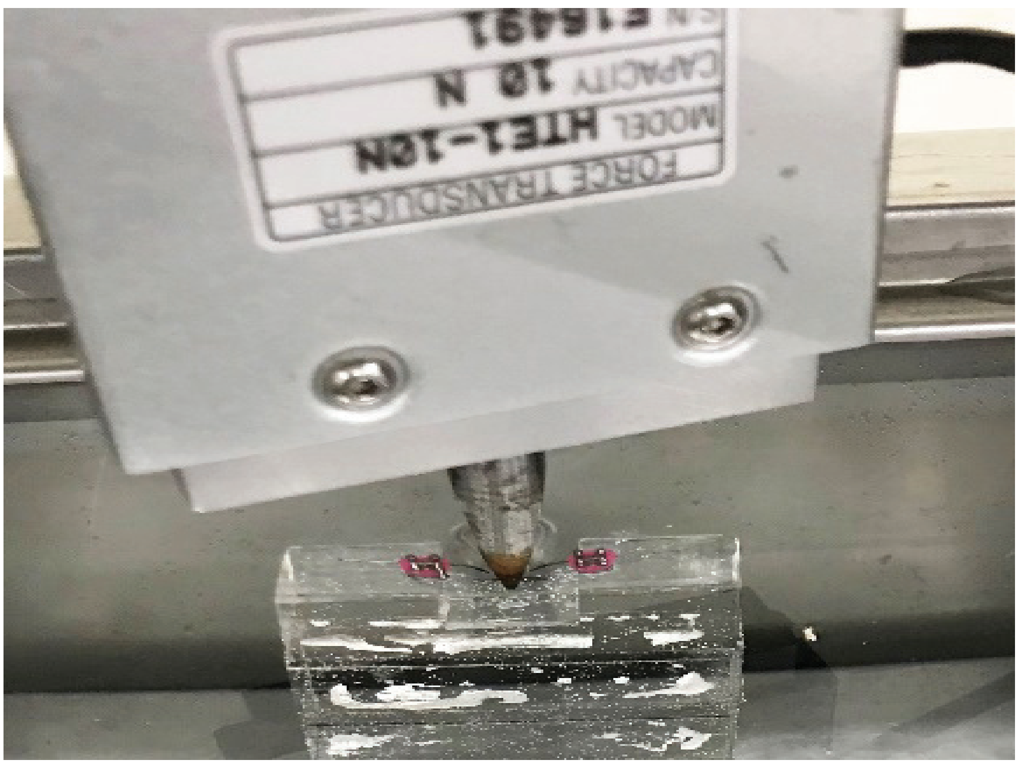

Figure 1: Wire segment during testing

Statistical Analysis

The data were analysed using SPSS software (SPSS Inc., Chicago, Illinois, USA) version26 for Windows. The Shapiro–Wilk test was used to assess the normality of variance between groups and showed normally distributed data. Thus, one-way analysis of variance (ANOVA) was used to compare the means of the groups. A p-value of < 0.05 denoted statistical significance.

Results

Figures2 and 3 show the load deflection behavior of the TiNbTaZr (Gummetal) archwire compared with the control (SE-NiTi and Cu-NiTi) archwires at 2 and 4 mm deflections, respectively. In figure 2, Gummetalarchwireexhibited higher loading and unloading curves as compared to SE-NiTi and Cu-NiTiarchwires. While, in figure 3 the loading curve of Gummetal was, to some extent, similar to that of SE-NiTi. They generated almost the same amount of force at maximum deflection; however,the forces weremarkedly higher than in the Cu-NiTiloading curve. It can also be shown in figure 3 that the unloading curve of Gummetalwas higher, steeper and reached zero force faster than that of the SE-NiTi and Cu-NiTiarchwires. But it is worth to note that at both deflections,narrower vertical distance between the loading and the unloading curves was observed forGummetal as compared with the control archwires.

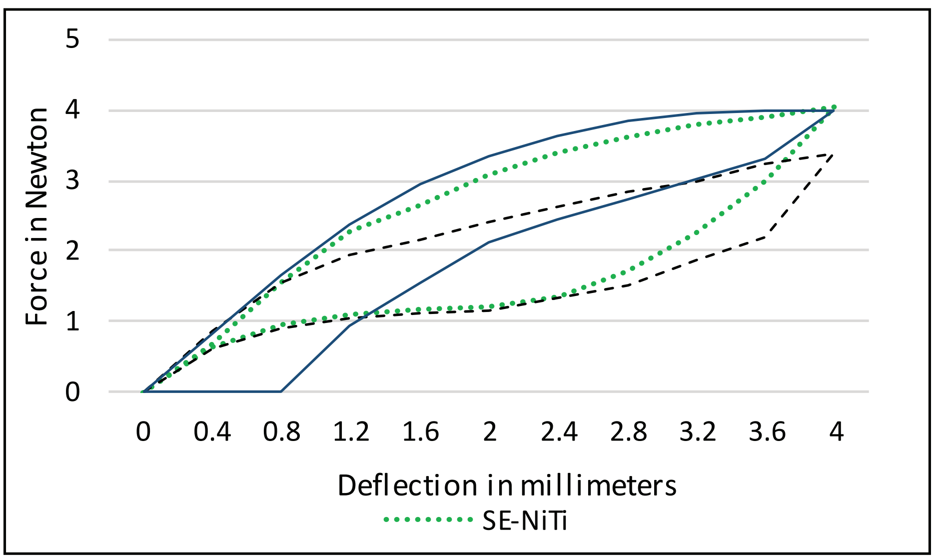

Figure2 Average load deflection behavior of TiNbTaZr (Gummetal), SE-NiTi and Cu-NiTi at 2 mm deflection

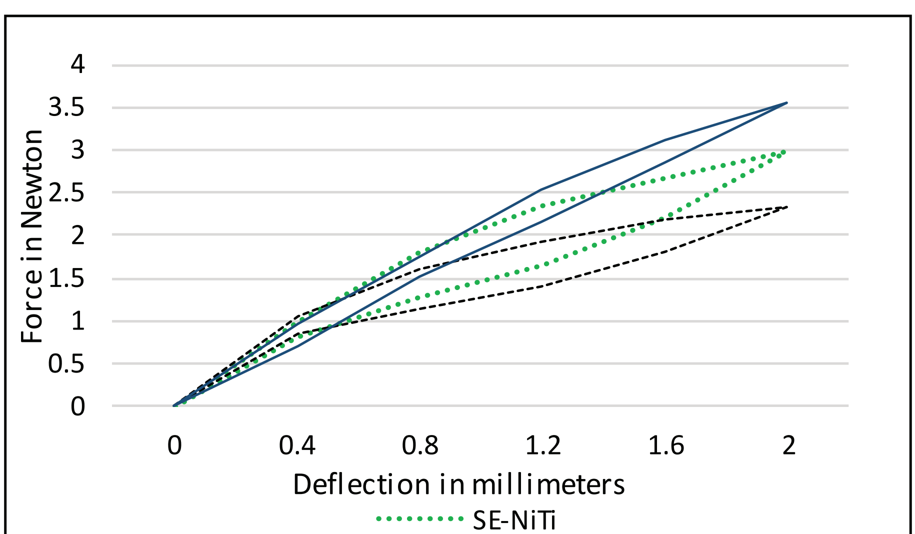

Figure 3 Average load deflection behavior of TiNbTaZr (Gummetal), SE-NiTi and Cu-NiTi at 4 mm deflection

In table 2, it can be observed that the mean force values produced by Gummetalwere significantly higher than those produced by SE-NiTi and Cu-NiTi at maximum deflection and at 1.5 and 1 mm unloading deflection points.

Table 2 Descriptive statistics and results of ANOVA (F-test) in N at maximum deflection (2 mm) and at 1.5 and 1 mm unloading deflection when the tested wires were deflected by 2 mm.

Deflection	Archwire	Mean	Min.	Max.	SD	F-test	P-value
2 mm (Max. deflection)	Gummetal	3.554	3.500	3.580	0.033	200.658	0.000
	SE-NiTi	2.981	2.876	3.068	0.078		
	Cu-NiTi	2.332	2.237	2.584	0.144		
1.5 mm	Gummetal	2.674	2.604	2.767	0.070	185.105	0.000
	SE-NiTi	2.049	2.00	2.115	0.054		
	Cu-NiTi	1.689	1.614	1.885	0.111		
1 mm	Gummetal	1.858	1.700	1.965	0.111	61.357	0.000
	SE-NiTi	1.445	1.413	1.527	0.047		
	Cu-NiTi	1.264	1.194	1.420	0.090		

Table 3 shows thatat maximum deflection (4 mm), TiNbTaZr (Gummetal) and SE-NiTi generated a comparable mean force values, which were significantly higher than those of Cu-NiTi. At the 3 and 2 mm unloading deflection points, Gummetal exerted significantly higher forces than either SE-NiTi and Cu-NiTi. However, at 1 mm unloading deflection point, the mean force values of Gummetal were significantly the lowest.

Table 3Descriptive statistics and results of ANOVA (F-test) in N at maximum deflection (4 mm) and at 3, 2 and 1 mm unloading deflection when the wires were deflected by 4 mm.

Deflection	Archwire	Mean	SD	Min.	Max.	F-test	P-value
4mm (Max. deflection)	Gummetal	4.008	0.264	3.71	4.31	8.796	0.004
	SE-NiTi	4.053	0.089	3.936	4.15		
	Cu-NiTi	3.398	0.388	2.725	3.716		
3 mm	Gummetal	2.876	0.097	2.78	3	98.019	0.000
	SE-NiTi	1.944	0.032	1.906	1.986		
	Cu-NiTi	1.751	0.212	1.377	1.888		
2 mm	Gummetal	2.111	0.128	1.95	2.251	132.616	0.000
	SE-NiTi	1.207	0.021	1.187	1.232		
	Cu-NiTi	1.162	0.125	0.95	1.275		
1 mm	Gummetal	0.644	0.041	0.585	0.695	32.164	0.000
	SE-NiTi	1.034	0.058	0.97	1.11		
	Cu-NiTi	0.978	0.125	0.77	1.1		

Discussion

When a new wire material is introduced toorthodontics, orthodontists should understand its properties in order to take full advantage of it during clinical practice, especially if the material considerably differs from the conventional one [(13).] A new beta-titaniumarchwire, named Gummetal, has been recently introduced to the field. Its characteristics include being highly elastic, formable and nickel-free [(14).]The goal of this study was to evaluate the load deflection properties of small-diameter TiNbTaZr (Gummetal) archwire in comparison with superelastic-

NiTi and copper-NiTiarchwires in an attempt to assess the mechanical efficiency of Gummetalas aligning archwire.

Load deflection properties of orthodontic wiresare considered the most important parameters in determining the biologic nature of orthodontic tooth movement[(15).] They are better assessed by three-point bending test, since it closely simulates the clinical situation to which orthodontic wires are being subjected and also has the ability to recognize wires with superelastic properties [(12).]In the principle of physics, it is recommended not to deflect a wire more than 5 per cent of its length, in order to ensure that the wire is being tested within the range of its metallurgical properties. However, in the present study, wire specimens were deflected by 2 and 4 mm, as such deflections are considered normal in the oral environment[(16,17).]

At 2 mm deflection Gummetalarchwireexhibited a higher loading curve than the SE-NiTi and Cu-NiTiarchwires, indicating that Gummetalarchwire requires higher forces to be engaged into the bracket slot. While at 4 mm deflection, Gummetal and SE-NiTiarchwires produced almost the same maximum force values.This could be related to deflection of the Gummetal wire beyond its elastic limit and that a plastic deformation had occurred in the wire.The vertical distance between the loading and unloading curves was narrower for Gummetal than for SE-NiTi and Cu-NiTiarchwires, both at 2 and 4 mm deflections. According to Segner and Ibesuch vertical distance represents the combined effect of hysteresis and friction [(11).] This can be true for NiTiarchwires, but for Gummetalthis distance might reflect friction and plastic deformation rather than hysteresis, becauseFuruta et al reported that Gummetal alloy exhibits no hysteresis [(18).]

Regarding the unloading (deactivation) force, which represents the force delivered to teeth during orthodontic treatment, a rank order of Gummetal > SE-NiTi > Cu-NiTi was found for the tested wires, both at 2 and 4 mm deflections. However, Gummetalarchwire exhibited a rapid decreasein force in comparison with the control wires, especially when it was deflected by 4 mm, in which unloading forceof Gummetal dropped to zero at 0.8 mm unloading deflection point, whereas SE-NiTi and Cu-NiTiarchwires were still giving minimal amount of force. This rapid decrease in the Gummetal unloading forcegives an indication that the wire has a lower springback effect and hence a reduced ability to produce continuous forces compared with the SE-NiTi and Cu-NiTiarchwires.

Despite the significantlyhigher forces produced by TiNbTaZr (Gummetal) compared to the control archwires, these forces are considered normal from a clinical perspective, as suggested by Rock and Wilson who considered forces of approximately 4 N to be appropriate for use with fixed orthodontic appliances [(19).] Additionally, a systematic literature review by Ren et al stated that the term “optimal force” is controversial, and forces that are considered to be high in a situation may be ideal in another [(20).] Nevertheless, it may not be suitable to consider Gummetalas superelastic wire, becausesuperelastic materials should exhibit a reversible change upon stress[21], and in this experiment Gummetalshowed permanent deformation during deflection.

According to these findings, the use of TiNbTaZr (Gummetal) archwire in the alignment stage of orthodontic treatment may be limited to mild crowding cases that do not require excessive deflection of the archwire, otherwise bending loops will be necessary to increase the flexibility and range of the wire.

Limitations:

Although laboratory studies can provide basis for comparing the behavior of different orthodontic wires, they cannot reflect clinical reality. In addition,in the present study only 0.014-inch diameter wires were tested and only in combination with one type of brackets (conventional metal brackets). Results might be different if another wire dimension (e.g., 0.016 or 0.018 inches) and/or another type of bracket, such as self-ligating or esthetic brackets were used.

Conclusions

1. The study showed significant differences between the load-deflection behavior of TiNbTaZr (Gummetal) archwire and that of the NiTiarchwires.

2. Gummetal generated higher unloading forces in comparison with SE-NiTi and Cu-NiTi, at both 2 mm and 4 mm deflections.

3. Gummetal was less efficient than SE-NiTi and Cu-NiTi in providing continuous forces.

4. Gummetal cannot be considered superelastic.

5. The use of Gummetalarchwire in the alignment phase may better be limited to mild crowding cases.

Ethical Clearance: The Research Ethical Committee at scientific research by ethical approval of both environmental and health and higher education and scientific research ministries in Iraq

Conflict of Interest: The authors declare that they have no conflict of interest.

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