Original Article

Mechanical properties of beta-titanium wires

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ABSTRACT

Objective: To evaluate the force-deflection behavior of six beta-titanium wires using a three-point bending test.

Materials and Methods: The wires timolium (TIM), titanium molybdenum (ORG), beta titanium (BETA), resolve (RES), titanium molybdenum alloy (TMA), and TMA low friction (TMAL) were adapted into two stainless steel brackets, with no angulation or torque. Both brackets were bonded to an acrylic jig with a 10-mm interbracket distance. A testing machine (Instron) applied deflections of 0.2 to 2.0 mm. Force-deflection diagrams were determined from a passive position to an activation of 2 mm and then during deactivation. Forces of activation and deactivation at a deflection of 1 mm were compared by analysis of variance.

Results: Results demonstrated that significant differences ($P < .05$) in force were observed among wires. During activation, forces for the wires were ranked from lowest to highest as TMAL=TMA=RES<ORG=BETA<TIM. During deactivation, forces for the wires were ranked from lowest to highest as TIM<ORG=BETA<RES= TMA<TMAL. The wires exhibited similar activation-deactivation diagrams.

Conclusion: This study revealed significant differences in force during activation and deactivation among the six types of beta-titanium wires tested. (*Angle Orthod.* 2011;81:478–483.)

KEY WORDS: Beta-titanium orthodontic wires; Orthodontic wires; Titanium molybdenum alloy

INTRODUCTION

Orthodontic wires made from different alloys now offer alternative sequences of wire usage during all phases of orthodontic treatment. It is now possible to match phases of treatment with orthodontic wires according to the mechanical properties of the wire. On this basis, the selection of orthodontic wire should be based not only on the transverse section of the wire, but also on an understanding of the deactivation characteristics of the wire required for different phases of orthodontic treatment.[1–3]

The beta-titanium (β-Ti) wires are titanium molybdenum alloys, introduced for orthodontic use in 1979 by Goldberg and Burstone.[4] These investigators envisioned this alloy for orthodontic use after recognizing such advantages as (1) elastic modulus below stainless steel and near to nickel-titanium (NiTi) conventional alloy, (2) excellent formability, (3) weldability, and (4) low potential for hypersensitivity.[5,6] However, use of β-Ti wire has disadvantages such as (1) high surface roughness, which increases friction at the wire-bracket interface during the wire sliding process, and (2) susceptibility to fracture during bending.[7–11] To reduce surface roughness, a nitrogen ion implantation technique has been used. However, some authors[12–14] have questioned the effectiveness of this process in the reduction of friction.

Initially, β-Ti wires were used for specific application in a segmented arch technique for making of retraction loops. Recently, β-Ti wires have been used in the construction of an intrusion arch[15] and an uprighting molar spring. Also, β-Ti wire is useful in cantilevers for intrusion or extrusion of teeth. All of these applications make it possible to individualize tooth movement and still provide a controlled force system.

In 1992, Hilgers[16] described the pendulum appliance for distal molar movement performed with 0.032-inch

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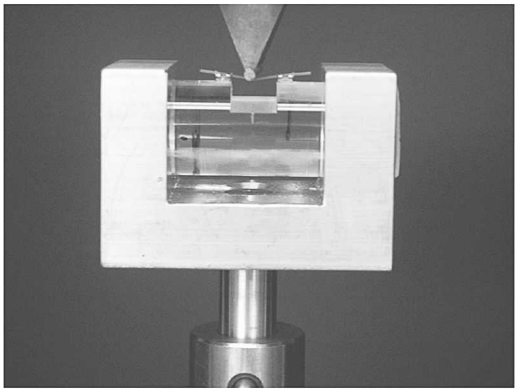

Figure 1. Load-deflection apparatus with the specimen under load.

β-Ti wire. This wire was chosen because it had stiffness of about one-half that of stainless steel. The pendulum springs increased the working range for molar distalization without permanent deformation, and the amount of force used was less than that of steel for the same activation.

For the past 20 years, Ormco (Glendora, Calif) has had the exclusive patent on β-Ti wire, which was sold as TMA (titanium molybdenum alloy). However, since 2000, other companies have introduced β-Ti wires.[14,17,18] A major concern is now activation-deactivation behavior of each of the new β-Ti wires being marketed.

The mechanical properties of other wires from different alloys have been evaluated in several studies.[1,19–22] These evaluations represent an important parameter in achieving optimal tooth movement. It is important for orthodontists to have reliable information about the mechanical properties of commercial β-Ti wires.

The purpose of this research was to evaluate the force-deflection behavior of different commercial β-Ti wires when submitted for activation and deactivation during a deflection test.

MATERIALS AND METHODS

The deflection test utilized a device fabricated to allow one-point deflection using two brackets. This design resembled a five-point deflecting system,[23] in which the brackets were used as lateral support for a 14-mm wire span between brackets. The device had a 10-mm-diameter acrylic rod adapted to a metallic frame. Brackets (0.018 × 0.025 inch) without angulation or torque (S4-02k twin mini, Morelli, Sorocaba, Brazil) were then bonded to this rod (Figure 1). Six different 0.017 × 0.025-inch β-Ti wires, 14 mm in length and marketed by five companies, were tested (Table 1). Five specimens of each wire were placed individually in the bracket slot and ligated with elastomeric ligatures (Class One Orthodontics, Lubbock, Tex).

Table 1. Codes and Manufacturers of Beta-Titanium Wires Tested

Code	Wire	Manufacturer
TIM	Timolium	TP Orthodontics Inc., Westville, Ind
ORG	Titanium-molybdenum	Ortho Organizers, Carlsbad, Calif
BETA	Beta III titanium archwire	3M Unitek, Monrovia,Calif
RES	Resolve	GAC, Islip, NY
TMA	TMA	Ormco, Glendora, Calif
TMAL	TMA low friction	Ormco, Glendora, Calif

After adaptation of each wire specimen, the acrylic rod was attached to the support utilized for the deflection test. Loading was achieved through movement of a metal loading device adapted on a mechanical testing machine (Instron Corp, Canton, Mass) with a 5-kg load cell and a crosshead speed of 0.5 mm/min. The force/activation curve was measured from the passive position to an activation of 2 mm, then back to zero. The load was applied in intervals of 0.2 mm, from 0 to 2.0 mm, during loading and unloading to obtain representative load-deflection characteristics for each wire.

Means and standard deviations ($n = 5$) of the forces generated at activation and deactivation for a deflection of 1 mm were selected for statistical comparison of the data. Data were analyzed by analysis of variance (StatView, SAS Institute, Cary, NC). Means were compared using a Fisher's PLSD (protected least significant difference) interval calculated at the .05 level of significance.

RESULTS

Means and standard deviations of activation and deactivation forces of the wires measured at a deflection of 1 mm are listed in Table 2 and are shown graphically in Figures 2, 3, and 4. Activation and deactivation deflections of 1 mm were selected to establish a comparison parameter at the midpoint of the loading and unloading deflection used in this study.

Table 2. Forces for Activation and Deactivation for a Deflection of 1 mm Listed in Order of Increasing Deactivation Force*

	Activation Force, g		Deactivation Force, g	
Wire	Mean	Standard Deviation	Mean	Standard Deviation
TIM	168[a]	7	27[d]	2
ORG	141[b]	2	40[e]	4
Beta	141[b]	5	42[e]	2
RES	124[c]	5	58[f]	1
TMA	119[c]	4	61[f]	0.7
TMAL	116[c]	6	74[g]	4

* Different letters represent statistically significant differences.

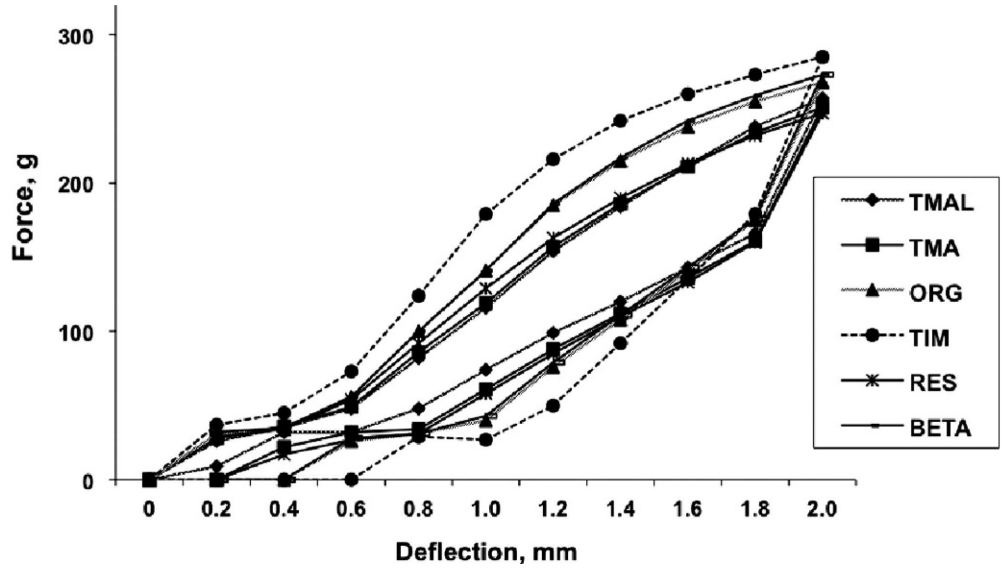

Figure 2. Load-deflection curves for beta-titanium wires during activation and deactivation.

Analysis of variance of activation and deactivation forces showed significant statistical differences among wires.

During activation, forces for the wires were ranked from lowest to highest as TMAL=TMA=RES<ORG=BETA<TIM (TMAL indicates TMA low friction; TMA, titanium molybdenum alloy; RES, resolve; ORG, titanium molybdenum; BETA, beta-titanium; and TIM, timolium). During deactivation, forces for the wires were ranked from lowest to highest as TIM<ORG=BETA<RES= TMA<TMAL.

With the same amount of activation (1 mm), three of the tested wires (RES, TMA, and TMAL) exhibited the lowest range of moments with force between 115 and 125 g, while BETA and ORG had forces between 140 and 145 g. TIM showed the highest force during activation (168 g). At the same level of deflection (1 mm) during deactivation, the force for TMAL was 74 g. TMA and RES had forces of 61 and 58 g, respectively. ORG and BETA had forces of 40 to 42 g, and TIM exhibited the lowest force at 27 g. Statistical differences were found in all force levels above the described activation and deactivation (Table 2).

DISCUSSION

Beta-titanium wires have been utilized in orthodontics because of their favorable characteristics such as low stiffness, excellent formability, and efficient working range for tooth movement. In fact, the only major disadvantage of this wire seems to be its cost. Initially used for springs and loops with segmented arches, β-Ti wires have become popular in all areas of orthodontic treatment. With an elastic modulus be-

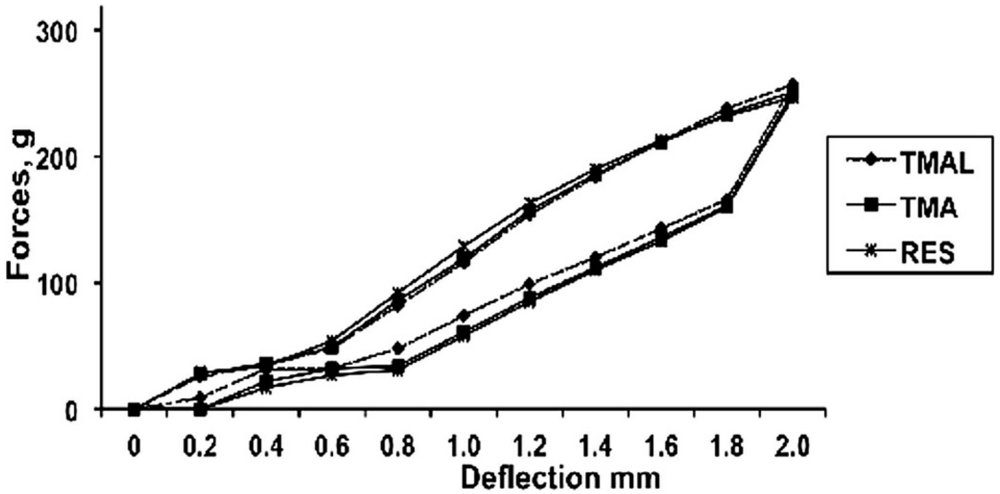

Figure 3. Load/Unload deflection graph for TMAL, TMA, and RES.

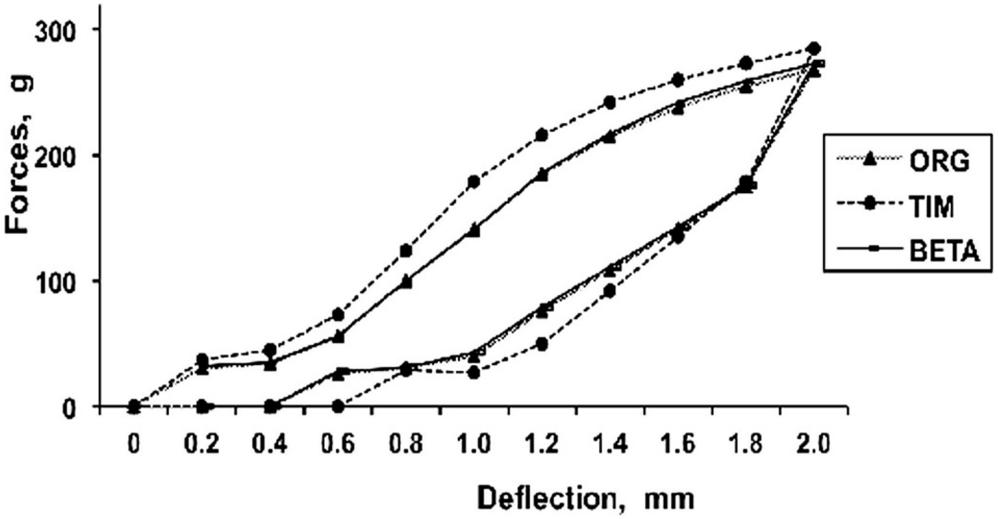

Figure 4. Load/Unload deflection graph for ORG, TIM, and BETA.

tween those of nickel-titanium and stainless steel alloys, the β-Ti wires are very efficient in situations requiring individual tooth movement. The pendulum appliance is a good example of the successful use of β-Ti wire. Although 0.032-inch stainless steel wire exhibits high stiffness, reduced springback, and forces incompatible with optimum biological dental movement, β-Ti wire of the same size affords optimal force to promote molar distalization with normal tissue reaction. Cantilever and three-piece archwires are other useful clinical applications of β-Ti wire.

Presently, no ideal orthodontic wire is available. The ideal situation for the orthodontist is to understand the specific characteristics of each orthodontic wire and to be aware of the appropriate uses of each type of alloy. Because of the multistage processing required for β-Ti wire, few companies in the world manufacture this titanium alloy. It is important that the quality control process of β-Ti wire and other orthodontic wires be strictly maintained. All companies that market these wires should provide their activation-deactivation force range.

Despite the inherent excellent formability of β-Ti wire, this wire processing can be problematic because of the reactivity of titanium that can result in some batches of β-Ti wire being susceptible to fracture during clinical manipulation.[24]

Laboratory tests do not necessarily reflect the clinical situation, but these tests provide a basis for comparison of different wires[11] and are used in many studies[1,6,9,14,17,18,20–23,25–28] in the literature.

Although this in vitro test was designed to simulate a deflection inducing tooth movement, β-Ti wires showed plastic deformation during activation. The force-deflection curves distinguished wires that exhibited more plastic deformation than others (Figures 3 and 4). TIM, ORG, and BETA required greater force to deflect and had more plastic deformation at the end of the deactivation curve. Therefore, it is advisable that β-Ti wire be selected for clinical situations that need bends like T loop or cantilever. The findings of this study suggest that the wires TIM, ORG, and BETA should be recommended for archwires with such bends.

The β-Ti wires tested exhibited statistical differences, indicating the existence of different forces for the same amount of deflection. Among the six types of wires analyzed in both activation and deactivation phases, only the TIM wire exhibited forces different from the others. The TIM wire exhibited the highest force on activation, indicating that TIM has higher stiffness during deflection. However, in the deactivation phase, TIM showed inadequate force necessary to promote dental movement after deflection of 2 mm. At a deactivation deflection of 1 mm, TIM produced a force of 27 g. This force is not enough to induce the biological response needed to produce dental movement in most patients.[29] The TIM wire did not exhibit favorable properties in deflection at 2 mm for leveling and alignment.

The TMAL wire also showed forces different from those of the other wires tested. With activation of 1 mm, TMAL showed low forces, statistically equal to forces of TMA and RES. In the deactivation curve, TMAL had 74-g forces, the lowest unloading force of the group. This finding could answer a question regarding nitrogen ion implantation on the surface of wire and its influence on wire strength. The low deactivation force (74 g) suggests that titanium nitride on the surface of TMAL only aids the reduction of friction.

TIM wires produced a variation in force-deflection behavior consistent with a reported description of molybdenum addition in the alloy.[24] Molybdenum aids in stabilization of the β-phase of titanium alloy and enhances the formability. The addition of zirconium and zinc contributes to an increase in strength and hardness, but this process can be problematic and makes the alloy susceptible to fracture. In fact, it was observed that TIM wire presents a different composition; this fact could contribute to variations in its stiffness.[1,6]

Although significant statistical differences ($P < .05$) were noted for TIM in activation and for TIM and TMAL in deactivation, other wires had similar activation and deactivation curves. In comparing the force-deflection curves of wires, it is clear that the curves are similar for RES, TMA, and TMAL (Figure 3). Also, it is possible to recognize a near fit among the curves of wires BETA, ORG, and TIM (Figure 4). This fit indicates that perhaps two distinct types of β-Ti wire are being produced—with different specifications, or as the result of two manufacturers processing this alloy for orthodontic use. The hysteresis curves of TMAL, TMA, and RES (Figure 3) presented a smaller interval between activation and deactivation segments; this represents a more flexible type of β-Ti wire.

BETA, ORG, and TIM wires represented a group of more rigid wires. These wires showed hysteresis curves with a larger interval between activation and deactivation phases (Figure 4). These groups of wires may be more suitable in any phase of orthodontic treatment that requires loops or other bends.

CONCLUSIONS

- This laboratory study showed that significant differences in force exist during activation and deactivation among the six types of beta-titanium wires tested.

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