Evaluation of Force Deflection Properties of Various Types of Initial Orthodontic Archwires

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ABSTRACT

Aim: The aim of this study was to compare the mechanical properties (force deflection) of five different types of archwires used in initial stage of orthodontic treatment.

Materials and methods: A modified three-point bending test was performed on the sample of 75 wires of conventional stainless steel, multistranded stainless steel, superelastic NiTi, thermal NiTi and multistranded coaxial NiTi (15 each). The load exerted by each of the wire was measured at the deflections of 0.5, 1, 1.5 and 2 mm during loading and subsequent unloading process at 37°C temperature.

Results: Force-deflection diagrams were determined from the passive position to an activation of 2 mm and then during deactivation forces on deactivation (unloading) at a deflection of 0.5, 1, 1.5 and 2 mm were compared by post hoc Tukey’s analysis of variance. Significant differences (p<0.05) in deactivation forces were observed among wires. The multistranded stainless steel wire had the lowest mean deactivation force (0.82 N), while the conventional stainless steel group had the highest mean value (3.56 N).

Conclusion: The multistranded coaxial NiTi wires exhibited lighter and more continuous forces hence should be the first choice of wire during the initial stages of treatment followed by thermal NiTi and superelastic NiTi. Multistranded stainless steel wires can also be considered as an economical alternative to more expensive NiTi wires.

Keywords: Initial orthodontic archwires, Mechanical properties, Loading and unloading forces, Orthodontics.

How to cite this article: Khatri JM, Mehta VP. Evaluation of Force Deflection Properties of Various Types of Initial Orthodontic Archwires. J Ind Orthod Soc 2014;48(4):309-312.

Source of support: Nil

Conflict of interest: None

Accepted after Revision: 4/2/14

INTRODUCTION

A fixed orthodontic appliance therapy is a treatment modality based on the theory that by applying light continuous force to a tooth, it can be moved optimally through the alveolar bone of the jaws without causing permanent damage. It follows the principle of elastic energy storage and its conversion into mechanical work through tooth movement. Each time the orthodontic appliance is adjusted it stores and controls the transfer mechanism and distribution of forces. An optimal control of tooth movement requires the application of a system of special forces which is properly supported by accessories, such as orthodontic wires, brackets, ligature ties, etc.

One such vital accessory of fixed orthodontic appliance is the archwire. An ideal archwire should be able to move teeth with a light, continuous force. This force should be designed to minimize patient discomfort, tissue hyalinization and root resorption. When a force is applied, the archwire should behave elastically over a period of weeks to months.

The force in play to align and level the teeth is not the activation force but the deactivation force, or unloading force, of the appliance. The activation and deactivation behavior of a wire might not be the same. Therefore, force-deflection graphs generated during the activation (loading) and deactivation (unloading) cycles of a wire might not superimpose. Hence, knowledge of deactivation behavior is important to the clinician for optimal wire selection.

In contemporary practice, archwires most commonly used in initial stage of orthodontic treatment are multistranded stainless steel, conventional stainless steel, superelastic NiTi, thermal NiTi and recently multistranded coaxial NiTi (supercable) wires.

The knowledge of the mechanical properties of the wires can facilitate the choice of wire required to achieve a given orthodontic movement. As various wires are available for initial alignment purpose, a need was felt to assess the physical properties of wires and the superiority of one over the other, so that they can be used accordingly. The null hypothesis was that there would be no difference in the deactivation forces of the above five listed group of wires.

MATERIALS AND METHODS

Materials

- Conventional preadjusted edgewise appliance (MBT) stainless steel bracket with a slot of 0.022” (Navy orthodontic brackets—Libral Traders).
Seventy-five samples were tested, 15 round wires for each of 5 different groups [multistranded stainless steel, conventional stainless steel, superelastic NiTi, thermal NiTi, multistranded coaxial NiTi (Supercable)] (Table 1).

- Stainless steel ligatures
- An experimental model
- Universal Instron testing machine

**Methods**

To examine the relationship between wire deflections and load a modified three-point bending test was performed, as it reproduced conditions encountered clinically, with the wire constrained as part of a fixed appliance. A mechanical testing system (Universal Instron testing device) was used to measure the loading as well as unloading forces as it virtually eliminated any extraneous variables and is easily repeatable.

Two standard metallic preadjusted edgewise brackets (0.022") of Navy orthodontics (Libral traders) were attached to an metallic jig with 14 mm distance between neighboring wings because it is the average distance between the labial centers of mandibular lateral incisor and first premolar. A 40 mm wire was tied to the brackets with stainless steel ligatures by the same operator, using the same technique and was turned seven times using a Mathieu ligature tying pliers, then tucked under the bracket, in an effort to simulate the clinical method of tying with steel ligatures.

The specimens were then inserted into the system, which was filled with 37°C water. The entire test was performed at this temperature and by the same operator. The centers of each wire were deflected at a crosshead speed of 0.3 mm/min, with 100 N load cell. Each specimen was loaded until a deflection of 2 mm was produced thereafter they were deloaded (deactivated) at the same crosshead speed until the load became zero (Fig. 1).

The load exerted by each of the wire was measured at the deflections of 0.5, 1, 1.5 and 2 mm during loading as well as subsequent unloading process (Graph 1). This was then followed by another assembly of specimen. Fifteen samples of each type of wire group were tested. Therefore, a total of 75 samples were tested. Results obtained were analyzed statistically (Table 2).

**STATISTICAL ANALYSIS**

The data were collected, tabulated and statistically analyzed using the SPSS 18 version software. To find the significance between the mean loading and unloading forces for each of the wires a paired t-test was used. For the comparison of the mean loading and unloading forces, exerted by all the groups (intergroup comparison) post hoc Tukey’s analysis of variance (ANOVA) was used.

**RESULTS**

The null hypothesis was not accepted. The statistical analysis of the deactivation forces showed significant differences among the wires. Mean of activation and deactivation forces of all the wires measured at a deflection of 0.5, 1, 1.5, 2 mm and overall are listed in Table 2.

### Table 1: Size and manufacturers of the wires tested

<table>
<thead>
<tr>
<th>Sl. no</th>
<th>Type of wire</th>
<th>Size</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Multistranded stainless steel</td>
<td>0.015&quot;</td>
<td>GAC International</td>
</tr>
<tr>
<td>2.</td>
<td>Conventional stainless steel</td>
<td>0.014&quot;</td>
<td>G and H wire</td>
</tr>
<tr>
<td>3.</td>
<td>Superelastic NiTi</td>
<td>0.016&quot;</td>
<td>G and H wire</td>
</tr>
<tr>
<td>4.</td>
<td>Thermal NiTi</td>
<td>0.016&quot;</td>
<td>G and H wire</td>
</tr>
<tr>
<td>5.</td>
<td>Multistranded coaxial NiTi</td>
<td>0.016&quot;</td>
<td>Speed system</td>
</tr>
</tbody>
</table>

**Graph 1:** Representative force-deflection plot for superelastic NiTi
According to the performed statistical analysis:

- Multistranded stainless steel wires had the least unloading force at the deflections of 0.5 mm (0.07 N), 1 mm (0.13 N) and 1.5 mm (0.29 N) whereas multistranded coaxial NiTi had the least unloading force at the deflections of 2 mm (2.41 N).

- Conventional stainless steel wires had the maximum unloading force at the deflection of 1 mm (2.34 N), 1.5 mm (4.23 N) and 2 mm (7.24 N) whereas superelastic NiTi had the maximum unloading force at the deflections of 0.5 mm (0.75 N).

- The mean unloading force at all the deflections collectively was minimum for multistranded stainless steel wires, i.e. (0.824 N) followed by thermal NiTi wires, i.e. (1.130 N) and multistranded coaxial NiTi, i.e. (1.239 N). Whereas the unloading force was maximum for conventional stainless steel wires, i.e. (3.563 N) followed by superelastic NiTi, i.e. (1.477 N).

### DISCUSSION

The results of this study detected significant differences in unloading forces among various alignment archwires used. Conventional stainless steel wires had the highest mean unloading forces at the deflections of 1, 1.5 and 2 mm. It also had the highest mean loading (5.01 N) and unloading (3.56 N) forces at all the four deflections collectively. Since, the forces in play to align and level the teeth are the deactivation forces, a significantly high level of unloading forces delivered by these wires are not beneficial for tooth alignment. The results obtained in this study are in accordance with the study done by Cardoso C et al (2009) which has shown the highest (4.687 N) deactivation force among the group at 2 mm of deflection by stainless steel wire.

Multistranded stainless steel wires which displayed a significantly low level of unloading force evolved as a viable option for the alignment of teeth. It had the least mean unloading forces at the deflections of 0.5, 1 and 1.5 mm. It also had the least mean unloading forces (0.82 N) at all the four deflections collectively. Similar observations were made in the research performed by Taneja P et al, Cardoso C et al and Rucker BK et al. Although, these wires exhibited a lower force, they did not display a consistently low and moderately decreasing forces at different degrees of deflection as NiTi wires.

Anecdotal clinical evidence has suggested that NiTi alloy wires are more effective in initial tooth alignment because of their unique properties of superelasticity and shape memory. However, the forces exerted by the superelastic NiTi wires (1.47 N) were relatively larger than the forces exerted by the thermal NiTi, multistranded stainless steel wires and multistranded coaxial NiTi wires. According to the conducted study superelastic NiTi wires had the highest mean unloading force at 0.5 mm deflection. It had 2nd highest mean unloading forces at the deflections of 1, 1.5 and 2 mm. A study performed by Wilkinson PD et al (2002) also shown that superelastic NiTi wires provided the highest unloading values as compared to other heat activated superelastic NiTi and multistranded stainless steel for every test deflection.

Thermal NiTi wires had the 2nd lowest mean unloading forces at the deflections of 0.5, 1 and 1.5 mm. Hence, the unloading forces exerted by the thermal NiTi wires (1.13 N) were relatively very low and continuous in comparison to the superelastic wires (1.47 N). Only multistranded stainless steel wires had a deactivation force (0.82 N) lesser than the thermodynamic NiTi, but they did not display a consistently low and moderately decreasing forces at different degrees of deflection. The force almost decayed to 0 when it reached the deflection of 1 mm. In a study performed by Justin T, Evans W1 et al in (1998) they observed that heat activated NiTi wires failed to demonstrate a better performance than the cheaper multistranded stainless steel. In the study done by Wilkinson PD et al (2002), they observed that multistranded stainless steel and heat activated NiTi wires produced a range of comparable results, and NiTi gave the highest unloading values. Similar findings were observed by Cardoso C et al (2009) the heat activated NiTi produced unloading forces lesser than super elastic NiTi but more than multistranded stainless steel.

Multistranded coaxial NiTi wires (Speed supercable) are designed specifically to deliver less force. Supercable has revolutionized initial archwire design by combining...
the metallurgical benefits of nickel titanium wire with the mechanical advantages of a coaxial design. The result is an archwire that imparts extremely light forces when subjected to severe deformation. In this study they exerted a relatively low and continuous force during its unloading. At the deflections of 0.5, 1 and 1.5 mm it had a mean unloading force greater than and almost equal to the multistranded stainless steel and thermal NiTi wires respectively. It also had the 3rd lowest mean unloading forces at all the four deflections collectively. However, according to the study performed by Berger J9 (2003), both the 0.016" and 0.018" supercable wires exerted only 36 to 70% of the force of 0.014" solid nickel titanium wires. Comparing wires of the same diameter, 0.016" supercable demonstrated 65% less force than 0.016" solid superelastic wires, while 0.018" supercable exerted 78% less force than 0.018" solid superelastic archwires. In a study conducted by Sebastian B10 in 2012, it was observed that 0.016" coaxial superelastic NiTi wire proved superior to single-stranded 0.016" NiTi in its efficiency in relieving lower anterior crowding over a 12-week period.

However, further clinical studies need to be carried out to evaluate and compare the efficiency of the above tested wires, as this study being an in vitro, has a limitation of not simulating the oral conditions.

CONCLUSION

Based on the findings of this study, the following conclusions could be reached:

• The null hypothesis that there would be no difference in the deactivation forces among the five listed groups of wires, i.e. conventional stainless steel, multistranded stainless steel, superelastic NiTi, thermal NiTi and multistranded coaxial NiTi (supercable) wires was rejected.
• Conventional stainless steel wires exerted the maximum deactivation force. There was also a significant decrease in force during the subsequent unloading process.
• Multistranded stainless steel wires exerted a minimum deactivation force but there was a significant decay of force after initial unloading. Hence, they did not display a consistently low and moderately decreasing force at different degrees of deflection as compared to the NiTi wires.
• Thermal NiTi wires exerted a deactivation force lesser than all the other wires except the multistranded stainless steel wires. However, there was a steady a decline in the amount of force delivered during the unloading of wires.
• Multistranded coaxial NiTi wires exerted a deactivation force lesser than the superelastic NiTi and conventional stainless steel wires, i.e. the 3rd lowest force. These wires displayed a consistently low and moderately decreasing force at different degrees of deflection as compared to the all the other wires.
• Superelastic NiTi wires exerted a deactivation force lesser than conventional stainless steel wires but higher than multistranded stainless steel, thermal NiTi and multistranded coaxial NiTi wires. Moreover, there was a sharp decline in the amount of force delivered during the unloading of wires.
It can also be concluded that the multistranded stainless steel wires could be an economical alternative to the more expensive NiTi wires.

REFERENCES