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Original Article

Load-deflection characteristics of coated and noncoated nickel-titanium wires in self-ligating brackets using a modified bending test: An *in vitro* study

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ABSTRACT

Background: To determine and compare the force-deflection values of different types of nickel-titanium (NiTi) wires during unloading phase at varying deflections, that is 1 mm, 1.5 mm, 2 mm, and 2.5 mm, with the use of self-ligating ceramic brackets using modified bending test on a typodont under controlled temperature conditions.
Materials and Methods: In this *in vitro* study total of 45 wires of ovoid shape of three different NiTi wires – pseudoelastic NiTi (Group I), heat activated NiTi (Group II), and esthetic coated NiTi (Group III) for maxillary arch were tested after insertion in ceramic self-ligating brackets bonded to plastic teeth of phantom jaw .The maxillary left lateral incisor was removed to simulate a malpositioned tooth which acted as the load site, and load-deflection characteristics were measured during unloading using Instron, and data analyzed statically by two-way analysis of variance ,Tukey's *post hoc* test, intraclass correlation coefficient and Pearson correlation coefficient. A two-sided ($\alpha = 2$) $P < 0.05$ was considered statistically significant.
Results: When wires were compared at each deflection statistically significant difference was observed between the three groups of wires (Group I > Group II > Group III) at all the four levels of deflection except for Group II versus Group III at 1 mm, 1.5 mm, and 2 mm of deflection. Statistically significant difference was noted in mean load values for comparisons made at different deflections for each wire except for the comparison made at 1.5 versus 2 mm for Group II and Group III.
Conclusion: Overall comparison showed esthetic coated Ni-Ti wires gave significantly lower mean load values, followed by heat activated and pseudoelastic NiTi wires. Thus, heat activated NiTi wires are best suited in patients with severe malpositions/periodontitis, while for esthetically conscious patients esthetic coated NiTi can be used.

Key Words: Nickel titanium, testing, unloading, wires

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INTRODUCTION

An ideal orthodontic archwire should be able to move the teeth with light continuous force thereby optimizing the biological environment for tooth movement.[1,2] In the initial phases of treatment elastic wires of low stiffness, good spring back, strength, and a long range of action should be employed.[3]

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Among the various wires used, in Orthodontics, nickel-titanium (NiTi) wires have gained popularity as it fulfills all the requisites of wires to be used during the initial phase of alignment. NiTi wires are available as conventional Nitinol (a martensitic stabilized alloy which lost out on its popularity due to inferior properties), pseudoelastic Nitinol (an austenitic active alloy which shows stress-induced martensitic transformation exhibiting a property of "Superelasticity"), and thermoelastic Nitinol (a martensitic active alloy exhibiting thermally induced "shape memory" effect).[4]

Superelasticity is a property in which the stress value remains constant despite the strain change within a specific range, thus a given wire would apply lighter forces for varying amount of deflections.[4,5] While shape memory is the ability of the material to "remember" its original shape after being plastically deformed to austenitic phase in the oral cavity.[3,6] Thus, pseudoelastic and heat activated NiTi were included in the present study.

Considering the upward advent of esthetic-based dentistry the same had been combined with mechanics to produce reduced friction, improved oral hygiene, and reduced treatment time, whereby ceramic self-ligating brackets were introduced.[7,8] Thus, ceramic self-ligating brackets and esthetic coated NiTi wires were included in the study.

Most of the previous studies tested the mechanical properties of wire using the cantilever test or three-point bending and these tests posed a major disadvantage of poor reproducibility of results, inability to efficiently reproduce the superelastic behavior of NiTi wires and did not simulate the conditions encountered clinically.[2,9-15] The three bracket bending test[2,9,16] and the modified bending tests[17-20] are fairly newer means of testing the mechanical properties of wires. Similar to clinical conditions, the modified bending test, offers increased constraints in terms of friction because of the curvilinear path of the model and the bracket assembly to which the wire is ligated. Thus, the modified bending test, recommended by various authors to test the orthodontic wires was used in this study.[17-20]

It has been noted that some wires behave differently under different temperature conditions.[21-24] Lowering the temperature of a superelastic archwire provides a longer working range as phase transition occurring at the temperature of the oral cavity will be delayed, hence this enhances its ability to adapt to a condition such as crowding.[25] Thus, to standardize and to keep a uniformity of comparison a water bath with controlled temperature at 37°C was included in the study design, that also helped in simulating the oral environment.

The aim of the current study was to determine and compare the force-deflection values of three different types of NiTi wires during unloading phase (ULP) at varying deflections, that is, 1 mm, 1.5 mm, 2 mm, and 2.5 mm, with the use of self-ligating ceramic brackets using modified bending test on a typodont under controlled temperature conditions.

MATERIALS AND METHODS

in this *in vitro* study Three types of ovoid-shaped NiTi wires (Group I-pseudoelastic NiTi [3M Unitek], Group II-heat activated NiTi [3M Unitek], and Group III-esthetic coated NiTi [G and H Wires]) for maxillary arch of similar cross-sections 0.016-in dimension were used.

A phantom jaw with plastic teeth was used to simulate the maxillary arch with a full complement of aligned teeth. For the purpose of our study, a maxillary left lateral incisor was removed to simulate a malpositioned tooth which acted as the load site. Tooth-colored, ceramic passive self-ligating brackets of MBT series with 0.022 slot and a unique NiTi Smart-Clip for passive ligation (CLARITY™ SL by 3M Unitek) along with double buccal tubes were used.

To test the wires under the desired temperature of 37°C, the phantom head model was immersed into a plastic water bath with a precalibrated K-type thermocouple with proportional temperature control up to 1°C and a digital thermometer. Load-deflection characteristics of all wires were measured using the Instron 1195 (High Wycombe, UK) at the Department of Material Sciences at IIT, Kanpur. It was fitted with a 50 kg load cell calibrated on a 2 kg range with 2 kg standard weight and moving at a crosshead speed of 1 mm/min. A chisel end attachment, used to deflect the wire at the load site was attached to the upper compartment of the machine and set of phantom jaw immersed in water bath was kept on the lower compartment of the machine.

For the test, wires were deflected up to 3 mm at the site of missing lateral incisor using Instron [Figure 1].

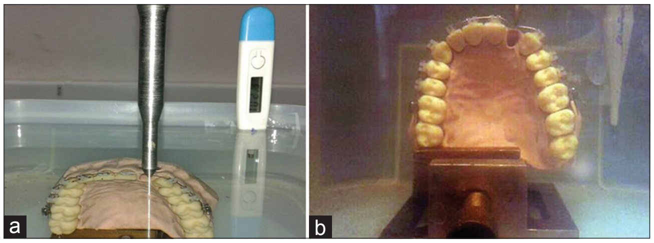

Figure 1: (a) Plunger at the load deflection site, (b) deflection by plunger.

The results were obtained as numerical value, and loading and unloading plots were obtained as graphs. The loading plot of the graph is seen when the orthodontic archwire is forcefully engaged into the bracket slot of an appliance and energy is stored. This stored energy when released gives us the corresponding unloading plot which brings about tooth movement during deactivation of the wire. Thus, the behavior of any orthodontic wires will be evident during unloading, hence, the unloading plot was considered in the study.

Measurement of reliability

To see the reliability of the load data, the load deflection of coated and noncoated NiTi orthodontic wires were intra and inter assayed on seven randomly selected samples after 1 week on the same instrument and another instruments in random order respectively and no significant difference was noted between the two sets of readings.

Statistical analysis

Data were summarized as mean ± standard error. Groups were compared by two-way analysis of variance, and the significance of mean difference within and between the groups was done by Tukey's *post hoc* test. The intra- and inter-assays variability were analyzed using intraclass correlation coefficient and Pearson correlation coefficient analyses, respectively. A two-sided (α = 2) $P < 0.05$ was considered statistically significant. All analyses were performed on IBM SPSS (statistical package for the social sciences) statistics. V. 23 (windows version 20.0).

RESULT

The load value measurements were calculated at four deflection levels during ULP:

- Level 1: At 1 mm during ULP
- Level 2: At 1.5 mm during ULP
- Level 3: At 2 mm during ULP
- Level 4: At 2.5 mm during ULP.

The mean load values of wires of Group I, II, and III at four defection levels during ULP are summarized in Table 1 and depicted in Figure 2.

The mean load between the deflections (within groups) for each wire and the mean load values at each deflection between the groups of wires were compared and summarized in Tables 2 and 3 respectively.

DISCUSSION

The results of the present study indicated a statistically significant decrease in the mean load value of each group of wire when the wire was unloaded from 2.5 mm to 1 mm. When wires were compared at each deflection statistically significant difference was observed between the three groups of wires (Group I > Group II > Group III) at all the four levels of deflection except for Group II versus Group III at 1 mm, 1.5 mm, and 2 mm of deflection. Statistically significant difference was noted in mean load values for comparisons made at different deflections for each wire except for the comparison made at 1.5 versus 2 mm for Group II and Group III.

A direct comparison with many of the previous studies was not possible because they differed either in the method of testing or the cross-section of the wire used or the bracket prescription employed.

Among the studies using similar modified bending test, Wilkinson *et al.*[18] performed a study using pseudoelastic NiTi and heat activated NiTi of 0.016-in dimension. A controlled water bath was used with three different temperatures, which was, 22°C, 35.5°C, 44°C. As in our study, we took standard temperature to be 37°C the comparisons with this study were made with the mean load values corresponding to 35.5°C. It was seen in their study that the heat activated NiTi delivered least amount of load during unloading, that is, 156 g at 1.5 mm deflection and 116 g at 1 mm deflection as compared to pseudoelastic NiTi, which gave force values as high as 256 g and 196 g at 1.5 mm and 1 mm deflections respectively. In our study also, a similar result was derived, wherein the mean load value seen at 1.5 mm and 1 mm deflections were less for heat activated NiTi (135.62 g and 102.5 g, respectively) as compared to pseudoelastic NiTi (199.99 g and 142.98 g). In our study, a reduction in the mean load values was observed in comparison to Wilkinson's study for both pseudoelastic and thermoelastic wires. This could be

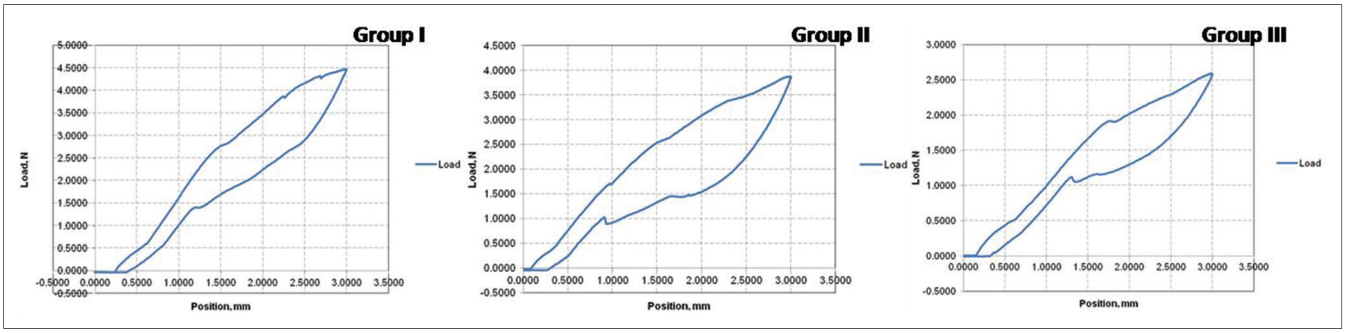

Figure 2: Loading and unloading plot of Group I, II, III wires.

Table 1: Load values (*n*=15) of three wires at four deflections

Wires	Load at different deflections			
	Level I Load at 1.0 mm (g)	Level II Load at 1.5 mm (g)	Level III Load at 2.0 mm (g)	Level IV Load at 2.5 mm (g)
Group I	142.98±8.23	199.99±7.21	246.57±7.45	309.63±5.66
Group II	102.50±3.09	135.62±4.56	164.89±4.40	229.37±5.18
Group III	85.81±4.33	122.38±1.87	144.30±1.80	187.02±3.03

Table 2: Comparison of mean load values of each wire between the deflections (within groups)

Deflection	Group I	Group II	Group III
1.0 mm versus 1.5 mm	<0.001	<0.001	<0.001*
1.0 mm versus 2.0 mm	<0.001	<0.001	<0.001*
1.0 mm versus 2.5 mm	<0.001	<0.001	<0.001*
1.5 mm versus 2.0 mm	<0.001	<0.003	0.106
1.5 mm versus 2.5 mm	<0.001	<0.001	<0.001*
2.0 mm versus 2.5 mm	<0.001	<0.001	<0.001*

*$P<0.001$: Significant

Table 3: Comparison of mean load values at each deflection between the groups of wires

Comparisons	1.0 mm	1.5 mm	2.0 mm	2.5 mm
Group I versus Group II	<0.001	<0.001	<0.001	<0.001
Group I versus Group III	<0.001	<0.001	<0.001	<0.001
Group II versus Group III	0.483	0.809	0.169	<0.001

*$P<0.001$: Significant

because the smart clips at the mesial and distal ends of the ceramic self-ligating bracket with metal inserts would offer less binding of the round archwire as compared to the clips of Twin lock metal self-ligating brackets of Wilkinson's study, that lie over the labial surface in the center of the slot, consequently providing more binding and hence increased friction. For heat activated NiTi, transition temperature range is very important because the wire undergoes phase change from martensitic to austenitic in oral cavity. This change could be better accomplished on carrying out test at 37°C instead of 35.5°C as mentioned in the above study.

Wilkinson *et al*.[18] also compared the three modes of bending, that is three-point bending, three-bracket bending (partial acrylic model) and modified bending tests (full arch acrylic models). It was thereafter concluded by them that the modified bending test gave higher mean load values followed by three bracket bending and then by three-point bending. Thus, they suggested that the modified bending test is a better test for analyzing the mechanical properties of wires as compared to the three point-bending tests which was previously thought to be a better test.

In another study by Gurgel *et al*., wires of 0.017 × 0.025 - in dimension were tested using modified bending test in metal brackets under controlled temperature of 35°C, and it was concluded that pseudoelastic NiTi wires exerted less force on deactivation.[17]

In yet another study done by Parvizi and Rock,[19] the mechanical properties of thermal NiTi was compared with pseudoelastic NiTi of 0.016-in dimension using modified bending test and beam test (three-point bending test). The three-point bending tests revealed no significant increase in force when deflection was increased from 2 mm to 4 mm while the modified bending test revealed that by increasing deflection there was a significant increase in the force produced by the wires. The three-point bending test revealed that the three thermoelastic wires tested behaved similarly as conventional NiTi with every 10°C rise in temperature. On the contrary, the modified bending test revealed that the thermally active NiTi produced significantly higher forces than the thermoelastic wires on rise of temperature from 20°C to 30°C. Further, the difference in force values with increase in temperature from 30°C to 40°C were not significant as the wire was demonstrating a superelastic behavior.

The load values, thus obtained at any deflection in the present study as well as in other studies conducted using modified bending test is much higher than the results obtained with three-point bending or three bracket bending test.[6,7,26] A study done by Oltjen *et al*. compared the three bracket bending and three-point bending tests utilizing a 0.016-in NiTi wire. It was observed that the stiffness from the three-bracket bending system for a given wire was about 1.5–4 times the value for the same wire in the three-point bending test at 1 mm and 2 mm of deflection.[2] An exception to this pattern was the nickel-titanium wire in three-bracket bending at 2 mm of deflection, where three point-bending values exceeded the bracket-bending values. At 3 mm of deflection, the stiffness values in bracket-bending exceeded the stiffness values in point-bending by 7.5–40 times. This difference was seen due to the property of superelasticity exhibited by NiTi wires, which could not be assessed effectively by the three-point bending test, thereby giving erroneous results that are not reproducible. Thus, the mechanical properties obtained by the modified bending test would represent the functioning of orthodontic wires in true sense.

Although the esthetic coated NiTi wires were never tested using the modified bending test, but in a study by Iijima *et al*.,[15] esthetic coated NiTi of 0.016-in dimension were compared with Sentalloy using three-point bending test and a lesser mean load value was obtained as the present study. Another reason that could explain the reduction in mean force values is that the Teflon coating over the wire reduces the dimension of the base archwire, that is, a 0.016-in dimension wire may essentially not be of 0.016-in but lesser thus the load registered would also be less.

Correlating the above findings clinically, it can be suggested that to reduce the discomfort to the patient, an archwire exerting less load at increasing deflection should be used to align severely malposed teeth. For such cases, the heat activated NiTi becomes the wire of choice as the load in contrast to pseudoelastic NiTi. It was observed that of all the three wires tested; the esthetic coated NiTi gave the lowest load deflection rate because of the reduced dimension of the wire due to the addition of a Teflon coating on the wire. Similarly, when facing the challenge of treating a periodontally compromised patient, orthodontically, the usage of wires with lesser load values like heat activated NiTi will be better.

It can be thus suggested that the modified bending test gives results that were more accurate and simulated the clinical environment more closely can be used to evaluate the mechanical properties of orthodontic wires in future.

CONCLUSION

- Overall comparison among the three groups of wires showed that the esthetic coated NiTi gave significantly lower mean load values, followed by heat activated NiTi and then by pseudoelastic NiTi. It was also noted that when all wires were compared at each deflection, it was observed that there was a statistically significant difference between the three groups of wires at all the four levels of deflection except for heat activated NiTi versus esthetic coated wires at 1 mm, 1.5 mm, and 2 mm of deflection
- Overall the load value increases with the increase in each deflection and on comparing between different deflections for each wire it was noted that all comparisons showed statistically significant difference in mean load values except for the comparison made at 1.5 versus 2 mm for the heat activated NiTi and esthetic coated NiTi.

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Conflicts of interest

The authors of this manuscript declare that they have no conflicts of interest, real or perceived, financial or non-financial in this article.

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