

Original Research

Evaluation and Comparison of Load Deflection Rate of Four Arch Wires Used in The Alignment Phase of Fixed Orthodontic Treatment: An In-Vitro Study

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ABSTRACT

Aim: Adult patients warrant esthetic replacement for all the components of fixed orthodontic mechanotherapy. One of the latest advents is the esthetic archwire, Everwhite, properties of which have not yet been tested. Purpose of this study was to measure the load-deflection rate of esthetic archwire, Everwhite, and compare the same with that of three different types of archwires used in the alignment stage of fixed orthodontic treatment.

Materials and methods: A modified three-point bending test was performed to measure the load deflection rate. Sample consisted of 60 wires 15 each of superelastic Nickel Titanium (NiTi), Everwhite esthetic NiTi, thermal NiTi and multistranded coaxial stainless steel. Force per unit deflection for every sample was measured at 37°C for two different deflections (2 mm and 4 mm). Since the data was normally distributed ANOVA was performed to assess the difference in load deflection rate of four archwires. Tukey HSD post Hoc test was used to evaluate the intergroup difference.

Results: Comparison of mean load-deflection values revealed that thermal NiTi wires had lowest value at both 2 and 4mm deflection when compared to other three wires which was statistically significant ($p=0.009$). Superelastic and esthetic NiTi showed similar values of load deflection ratios at both the deflections whereas co-axial wire showed 1.89N at 2mm and 5.22N at 4mm deflection.

Conclusion: The heat-activated NiTi wires are acceptable in severe crowding and periodontally compromised patients. Multistranded co-axial wire is acceptable when we need minimal alignment; whereas esthetic NiTi wires can replace superelastic NiTi based on patient's need.

Keywords: Aligning archwires, Mechanical properties, unloading forces, esthetic archwire, load deflection rate.

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Introduction

In fixed orthodontic mechanotherapy, teeth are moved through alveolar bone of jaws by the application of light continuous force. This will ensure that there is minimal damage to the supporting periodontium.^[1] Force applied is stored as elastic energy in the periodontium which is transferred to alveolar bone to effect tooth movement. The same cycle repeats during every activation. The whole mechanism is supported by a proper appliance system with force generating elements and handles that transfer force to the teeth. Orthodontic brackets, arch wires, elastic ligatures etc. form some of the important components the force system.^[2]

Some of the desirable properties of orthodontic wires that are best suited for applying optimal force levels are large spring back, low stiffness, high formability, high stored energy, biocompatibility and weldable or to be able to solder auxiliaries and attachments.^[3-6]

One of the most desirable mechanical properties for an orthodontic archwire is low Stiffness or load deflection rate, which is the decline of force per unit deactivation of archwire. Low load deflection rate helps in maintaining desirable stress levels in the periodontal ligament.^[3] Factors that influence the load deflection rate are wire material, wire cross-section and wire length. Load deflection rate is proportional to modulus of elasticity (E) of the material.

Load deflection characteristics of orthodontic wire materials have been researched by various authors.^[7-13] Quintao et al studied the load deflection characteristics of different archwire materials and found out that stainless steel had the highest and superelastic, thermal nickel titanium (NiTi) and multistranded stainless steel wires had similar load deflection characteristics. It is to be noted that the deflection they had tested was for 2mm.^[12]

Demand for invisible orthodontics has led to the introduction of aesthetic wires. One of the most common ways of rendering orthodontic wires more esthetic is by coating them with different materials like Teflon, titanium dioxide, epoxy resin – polytetrafluoroethylene, rhodium etc.^[14-18] Everwhite is a new esthetic orthodontic archwire (American Orthodontics), esthetic and frictional properties of which have been tested by Bradley et al.^[14] Load deflection behavior of this new esthetic orthodontic archwire has not been tested before. Understanding the properties of coated wires and comparing the same with uncoated Nickel Titanium (NiTi), multistranded wires is important before a decision to use them can be justified. Therefore, purpose of the present study was to evaluate the load deflection rate of various round wires like super elastic NiTi arch wire, heat activated NiTi, multistranded co-axial stainless steel arch wire and aesthetic Everwhite NiTi arch wire. Null hypothesis can be stated as “There is no significant difference in the load deflection characteristics of the four orthodontic archwires”.

Materials and methods:

This invitro observational study was approved by the Institutional Review Board of SRM Dental College, Ramapuram, Chennai. Sample size was arrived at by using G power software version 3.0 with a power of 95% and alpha error at 0.05, total sample size arrived at was 60 (n=15 per group). The following three different arch wires commonly used during alignment stage in fixed orthodontic mechanotherapy were used in this study: 0.016” superelastic NiTi (3M Unitek), 0.016” thermoelastic NiTi (3M Unitek), 0.0175” Coaxial stainless-steel wire (3M Unitek). Load deflection rate of 0.016” Everwhite wire (American Orthodontics), new esthetic archwire was evaluated and the same was compared with other three wires.

Every sample was subjected to bending test to determine the load-deflection rate, using a Universal Testing machine with a load cell of 100N. Instead of the normal three-point bending test, archwires were tested after being engaged to brackets bonded to acrylic teeth on a typodont to simulate clinical scenario (Fig-1). Metal brackets (3M Unitek) were bonded to the artificial acrylic teeth from maxillary right second premolar to left second premolar and molar buccal tubes of 0.022” X 0.028” slot bonded to the maxillary first molar teeth on typodont using instant adhesive following MBT chart for bracket positioning. The maxillary right central incisor was removed so that an unengaged free wire segment of 16mm between maxillary left central incisor and right lateral incisor could be obtained to facilitate unhindered testing. Archwires were engaged to the brackets by using stainless-steel ligature ties. The ligature ties were preferred over modules to ensure least frictional force during testing.

For the purpose of testing, typodont was mounted on a universal testing machine after engaging the desired arch wire using a metal jig. Force of 100N was applied to cause deflection of 2mm and 4mm in such a way that each wire specimen of one of the materials tested underwent the same test for two different deflections subsequently after relaxation (Fig-1). Each archwire thus was ligated to the typodont archform before being subjected to three-point bending test. A software (EE2 Extensometer software) was installed to the universal testing machine which helped in measuring the applied forces, reading results instantly and providing the same in table (load-deflection rate).

Fig-1. Acrylic typodont with brackets bonded and wire engaged mounted on Universal testing machine. Maxillary right central incisor was removed to increase inter-bracket span to facilitate testing.



Statistical analysis:

Mean and Standard deviation were calculated from the results obtained (Table-1,3). ANOVA was used for comparison of the mechanical property tested since the data was normally distributed and p value < 0.05 was considered statistically significant. Tukey's HSD Post Hoc test was done to compare the difference between the groups at 2mm and 4mm deflection (Table- 2 and 4).

Results:

Statistical analysis of the load-deflection rate of four arch wires showed significant difference among the wires. Mean and standard deviation (SD) for the force at 2mm and 4mm deflection are ranked in Table-1,3. The heat activated NiTi had the lowest mean deactivation force (1.5N), second lowest mean load deflection is observed in multistranded co-axial stainless-steel wire while the superelastic and Ever white NiT shows higher value of 1.96N and 1.94N respectively. All these values were observed for 2mm of deflection. Statistical analysis of the load-deflection rate of four arch wires showed significant difference among the wires ($p=0.009$) (Table-1). Null hypothesis is thus rejected. Post hoc Tukey values are represented in Table-2 and it is clear that there was statistical significance when load deflection rate of heat activated NiTi wires were compared to other three arch wires.

When the mean and SD for 4mm of deflection (Table-3) were compared, there was a statistically highly significant difference between the groups ($p=0.000$). The highest load deflection rate was observed with coaxial wires (5.445N) followed by superelastic NiTi (3.942N), Everwhite wire (3.902N), the least was observed in heat activated NiTi (2.794N) group. Post hoc Tukey test also indicates statistically highly significant difference

between the groups (Table-4). This finding is in contrast to 2mm deflection where highest load deflection rate was observed in superelastic NiTi group followed by esthetic arch wire - Everwhite group.

Discussion:

As the first stage of the fixed appliance therapy is concerned with relief of crowding (alignment), effectiveness of this stage depends on several variables including mechanical properties of the wire materials used and biological factors. Biological factors like periodontal health, cellular and connective tissue response are outside the orthodontist's control, whereas the choice of the archwire is essentially made by the orthodontist. The favorable mechanical properties of orthodontic wires have an influence on the success of orthodontic treatment.^[1, 3]

Table-1 : One-way ANOVA to compare the mean load deflection between four orthodontic arch wire. Mean and standard deviation for the force at 2mm deflection of four arch wires shows significant p-value of 0.009

Wire type	N	Mean load – deflection (Newton's)	Std. Deviation	F-value	P-value
Heat-activated NiTi	15	1.525	0.1491	4.296	0.009
Coaxial SS	15	1.891	0.6114		
Ever white NiTi	15	1.947	0.2691		
Superelastic NiTi	15	1.962	0.2166		
Total	60	1.831	0.3922		

Ideal requisites of an orthodontic wire for aligning arch wires are low Stiffness or low load deflection rate. Load deflection rate is amount of force produced for every unit of activation of an orthodontic wire, and is proportional to modulus of elasticity; the lower the load-deflection rate, the smaller the force exerted for a given amount of displacement, and vice versa.^[3]

As a general rule, the transformation temperature of a nickel titanium alloy can be increased simply by increasing the ratio of titanium to nickel.^[4,5] The addition of copper to a nickel titanium alloy can also increase the transformation temperature. Thermal NiTi wires are recent introduction to the family of NiTi alloy wires.^[5]

Addition of copper has the potential to narrow the tolerance range of the transformation temperature and thus reduce the difference between loading and unloading forces. Copper NiTi is a quaternary alloy, which has distinct advantages over the formerly available nickel-titanium alloys.^[5] Since the unloading force is directly proportional to the difference between the transformation temperature and the working temperature (mouth temperature), elevating the transformation temperature decreases the alloy's unloading force. Krishnan et al compared super elastic NiTi with Copper NiTi and could observe a significantly lower hysteresis with Copper NiTi.^[6] The unloading forces more closely approximated loading forces. The loading factor reduction in Copper NiTi was 20% when compared to super elastic NiTi.

Table-2 : Tukey's HSD post hoc test for pair wise comparison of mean values for 2mm deflection

Wire Type	Wire Type	Mean Difference	P-Value
Coaxial-SS	Superelastic NiTi	-0.071	0.957
	Ever white NiTi	-0.057	0.978
	Heat activated NiTi	0.365	0.058
Super elastic NiTi	Ever white NiTi	0.015	0.999
	Heat activated NiTi	0.437	0.016
Ever white NiTi	Heat activated NiTi	0.422	0.022

Jones et al have concluded from their study that NiTi alloy wires are more effective in initial tooth alignment because of their unique properties of super elasticity and shape memory.^[19] However, according to the present study, forces exerted by super elastic NiTi wires (Table-1) at 2mm deflection (1.96N) were relatively larger than the forces exerted by thermal NiTi (1.52N) and multi stranded coaxial SS wires (1.89N). Super elastic NiTi wires had the highest mean unloading force at 2mm deflection (1.96 N). This result correlates with the study by Wilkinson et al which shows that superelastic NiTi wires exerted the highest unloading values as compared to other heat activated NiTi and multistranded stainless steel for every test deflection.^[8] Multistranded coaxial SS wires exerted a deactivation force of 1.89N at 2mm deflection that was lesser than the super elastic NiTi and esthetic wires.

Table-3 : One-way ANOVA to compare the mean load deflection between four orthodontic arch wire. Mean and standard deviation for the force at 4mm deflection of four arch wires shows significant p-value of 0.000

Wire type	N	Mean load –deflection (Newton's)	Std. Deviation	F-value	P-value
Heat-activated NiTi	15	2.79400	.004472	888367.50	.000
Coaxial SS	15	5.44500	.004472		
Ever white NiTi	15	3.90300	.004472		
Superelastic NiTi	15	3.94200	.004472		
Total	60	4.02100	.950496		

Though the esthetic NiTi wire (1.94N) shows similar load deflection rate compared to super elastic NiTi (1.96N), the choice of esthetic wires should be made after considering their pitfalls such as: transverse fractures, stress fractures with fiber detachment, fractures flush with the surface of the polymer/fiber interface, compression fractures originating in bends located in the fibers and fractures flush with the intralaminar surface.^[20] Everwhite wires had similar load deflection when compared to superelastic NiTi at 4mm deflection too. The selection of esthetic wires is strictly dependent on patient's demand for an esthetic appliance.

Table-4 : Tukey's HSD post hoc test for pair wise comparison of mean values for 4mm deflection

Wire Type	Wire Type	Mean Difference	P-Value
Heat activated NiTi	Coaxial NiTi	-2.651000*	.000
	Everwhite NiTi	-1.109000*	.000
	Superelastic NiTi	-1.148000*	.000
Coaxial-SS	Heat activated NiTi	2.651000*	.000
	Everwhite NiTi	1.542000*	.000
	Superelastic NiTi	1.503000*	.000
Ever white NiTi	Heat activated NiTi	1.109000*	.000
	Coaxial NiTi	-1.542000*	.000
	Superelastic NiTi	-.039000*	.000
Super elastic NiTi	Heat activated NiTi	1.148000*	.000
	Coaxial NiTi	-1.503000*	.000
	Everwhite NiTi	.039000*	.000

When the result at 2 mm deflection was statistically analyzed, the load deflection rate of all the four arch wires revealed a p value of 0.009 (Table-1) which was statistically highly significant. This reveals that thermal NiTi wire has the least load deflection rate and when compared with other three wires it stands with a considerable advantage of exerting least force per unit deflection. Similar results were observed when load deflection rate at 4mm deflection was applied (Table-3). This correlated with the results of Franaz Parvizi et al who compared thermal and super elastic NiTi found out that the thermal NiTi exerted least force per unit deflection of all the wires.^[9] Similar results were obtained in the study of Luca Lombardo et al who found that thermal NiTi exerted less average force.^[11]

This low load deflection of thermal NiTi would be very comfortable to the periodontal ligament and the supporting structures and greatly improves patient comfort. It would be acceptable to choose thermal NiTi in patients with severe crowding and compromised periodontal support for the same reason.

When intergroup difference was analyzed using post Hoc Tuckey's test (Table-2) it was found that results of thermal NiTi with all the three wires was significant, it was highly significant (p=0.016) with superelastic NiTi. Results of the present study have disproved the idea of superelastic wire as being the wire exerting less force when

compared to co-axial stainless-steel wire, but this value holds good only for minimal deflection of 2mm. Multistranded wire exhibited different behavior at a deflection of 4 mm (Table-3).

A study performed by Kusy and Dilley investigated strength, stiffness and spring back properties of multistranded SS wires in a bending mode of stress.^[21] They noted that stiffness of triple stranded 0.0175" (3 x 0.008 inch) SS arch wire was similar to that of 0.010" single stranded SS wire.

Comparison of the mean force generated by all the four wires recorded at 4mm and 2mm deflection was made and it was found that at 4mm deflection the coaxial wire had a force value of 5.22 N (Table-3) and the force decline from 4mm to 2mm was huge (5.22 N to 1.894 N) (Table-1). The mean force generated by coaxial wire was the highest at 4mm deflection (Table-3) when compared with all the other three wires; superelastic wire (3.98N), esthetic wire (3.86 N) and thermal NiTi (2.88 N). This indicated that the decline of force from 4 mm to 2 mm deflection was not consistent for coaxial wire. This finding of rapid fall in force level for coaxial wire was similar to the results of Taneja et al who concluded that multistranded wires had inconsistency in the fall of force at varying degrees of deflection.^[22] Hence, the choice of coaxial wire for initial stages of orthodontic treatment should be made in patients with minimal crowding.

A study by Ingram et al concluded that Titanium alloy wires and multistranded SS wires have low stiffness when compared with solid SS wires.^[23] Superelastic wire need not be the initial aligning arch wire of choice in all the patients. In patients with mild crowding, coaxial wire can be used as it has been shown to exhibit better comfort by the study of Sandhu et al who studied the pain perception of patients undergoing orthodontic treatment with 0.016" superelastic NiTi and 0.0175" multistranded stainless steel wire.^[24] They found that pain perceived by patients with superelastic wire was significantly greater than that of multistranded wire.

From the results of the study, it can be clinically correlated that in the alignment stages of orthodontic treatment heat activated NiTi wire is most preferable for cases with severe crowding; co-axial wire can be preferred over superelastic NiTi wire for some patients with minimal discrepancy and the choice of esthetic wire can be made dependent on the patient's need. Everwhite esthetic wire have similar load deflection values and they can replace superelastic wire with ease based on the clinical scenario. This research was done on four wires commonly used for alignment, one coated archwire could have been tested along with the four wires. The study could have been done on archwires coated with nanoparticles and attempts are being made to further research in the above-mentioned area by the authors.

Conclusion:

The following conclusions were arrived at based on the results of the study:

1. The heat activated NiTi group had the lowest mean deactivation force in both the deflections tested, which shows that it is very compatible to the periodontal ligament and the supporting structures and greatly improves patient comfort. It is acceptable to choose thermal NiTi in patients with severe crowding and compromised periodontal support for the same reason.
2. Superelastic and Everwhite NiTi exhibit comparable values of load deflection rates and it can be concluded that Everwhite esthetic wire can be chosen over superelastic NiTi if the patient demands it.
3. Multistranded co-axial wire exhibited different mean deflection forces (1.89N for 2 mm and 5.22N for 4 mm) for the two deflections. The decline of force from 4 mm to 2 mm was drastic. Hence coaxial wire may be used in patients requiring minimal alignment.
4. It can also be concluded that the heat activated NiTi wires could be an alternative to the expensive aesthetic NiTi wires.

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Conflict of Interest : None

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