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Comparison of the loading force among various esthetic archwires at different deflections

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Abstract

Introduction: The main objective of this study is to compare the loading force of different esthetic and conventional superelastic wires at varying deflections.

Material and Methods: Four different types of maxillary archwires (Group 1: Conventional NiTi, Group 2: Teflon coated, Group 3: Epoxy coated, Group 4: Polyurethane-coated) of 0.014-inch engaged in passive self-ligating brackets were tested at 2mm, 4mm, 6mm deflections by using a simulation model representing a dental arch. Force was applied on the midpoint of wire in the region of the left central incisor using Instron. The mean values of maximum loading force were recorded. One-way ANOVA and Tukey's test was used at $p \leq 0.05$ level of significance.

Results: Conventional NiTi wires showed an increase in force values as deflections increased. Coated wires have shown an increase in force values up to 4mm deflection.

Later on, there was a decrease in force value. The highest force was recorded for polyurethane-coated NiTi, followed by conventional NiTi, Teflon coated, and least was for the epoxy-coated wire.

Conclusion: Epoxy coated and Teflon coated archwires had shown lower loading forces than other wires at all deflections. Polyurethane-coated wires showed the highest loading force. Coated archwires demonstrated a reduction in loading forces beyond 4mm deflection.

Keywords: Polyurethane, Teflon, epoxy resin, polytetrafluoroethylene, orthodontic appliances

Introduction

Esthetics has become a prime concern in this modern era, as more adult patients are pursuing orthodontic treatment [1]. The introduction of esthetic materials beneficial to both patients in terms of providing acceptable esthetics and the clinician for better clinical performance is desirable.

Various approaches such as lingual orthodontics, clear aligners, and esthetic labial fixed appliances are the solutions for those who desire esthetic treatment [2,3]. Esthetic brackets made of ceramic or composites are being used on a broadscale for a long time.

Three esthetic archwires have been introduced, i.e., optiflex, [4] fiber-reinforced composite archwires [5], and coated metallic archwires. Materials used in the coating to stimulate tooth color are polymers such as synthetic fluorine-containing resin, epoxy, polytetrafluoroethylene (PTFE) [6].

Currently, the two most widely used aesthetic archwires are coated with either Teflon or epoxy resin. Epoxy resin is the commonly used coating material because of its excellent adhesion, chemical resistance, electrical insulation, and dimensional stability. Electrostatic coating or E – coating is used for Epoxy coating, giving a 0.002-inch-thick epoxy covering around the wire [7].

Polytetrafluoroethylene is a polymer consisting of carbon and fluorine and is better known as Teflon. PTFE is widely used due to its non-reactive, heat-resistant, and hydrophobic properties [7].

The Fiber Reinforced Polymer (FRP) archwire is manufactured with translucent composite material comprised of a polymethyl methacrylate matrix (PMMA) and glass fiber for reinforcement; the final product obtained is esthetic and have mechanical properties similar to coated Nickel-Titanium (NiTi) archwires. As they cannot withstand deflections of 2 mm without experiencing cracking and loss of force delivery usage of these FRP archwires might be less [8].

Surface treatment of coated wires might have an unfavorable effect on mechanical properties, including load-deflection rate, frictional properties, corrosion, and color stability of archwires in clinical conditions [9,10].

Hosseinagha et al. [1] studied the load-deflection characteristics of aesthetic and conventional NiTi archwires in conventional ceramic and metal insert ceramic brackets and stated that the uncoated NiTi archwires exhibit higher mean values of maximum loading and unloading than that of the coated archwires. Epoxy coated wires combined with Damon 2 self-ligating brackets produced the lowest forces in both loading and unloading compared to superelastic NiTi in conventional and Damon 2 self-ligating bracket combination [11].

Since Austenitic NiTi (A-NiTi) in passive self-ligating bracket system was determined to produce the lowest friction [12], was taken as a control in this study. The loading force and behavior of Teflon coated, epoxy coated, and polyurethane coated NiTi wires at 2mm, 4mm, 6mm deflections were compared A-NiTi in a 0.022 slot passive self-ligating bracket system using a uniquely designed jig simulating maxillary dentition with malocclusion.

Materials and Methods

Four different maxillary archwires of 0.014-inch size, from four different brands placed in passive self-ligating brackets of 0.022 slot were tested, which were divided into four groups as follows:

Group 1: Uncoated superelastic NiTi (GDC)–Figure 1

Group 2: Teflon coated NiTi (Modern orthodontics) – Figure 2

Group 3: Epoxy coated NiTi (Rabbit force) – Figure 3

Group 4: Polyurethane-coated NiTi (Morelli) – Figure 4

Figure 1: Uncoated superelastic NiTi (GDC®)

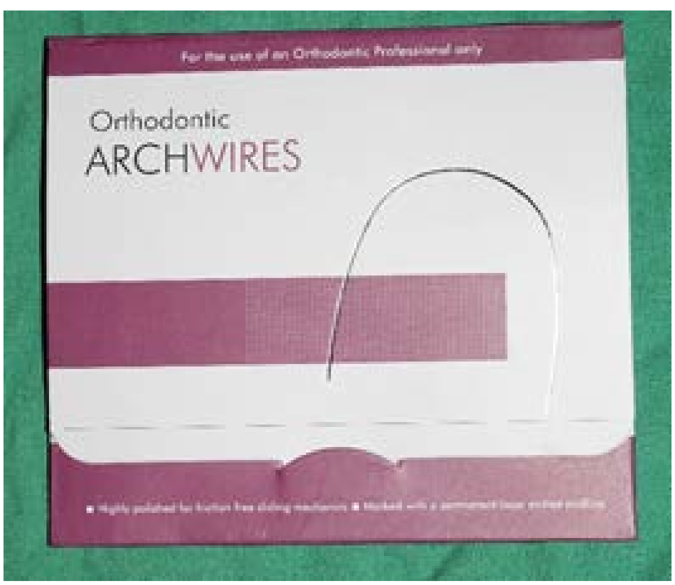

Figure 2: Teflon coated NiTi (Modern orthodontics)

Figure 3: Epoxy coated NiTi (Rabbit force)

Figure 4: Polyurethane-coated NiTi (Morelli®)

Figure 5: Maxillary typodont model

Typhodont jaw with acrylic teeth was used to simulate the maxillary arch. Maxillary left central incisor was taken off from the typhodont model, where the load was applied to deflect the wires, simulating a malposed tooth. 0.022 X 0.028-inch passive self-ligating brackets were bonded on the acrylic teeth of a maxillary typodont model along with the molar tubes (Figure 5). A passive slot lineup was achieved before light curing the composite using a 0.021 X 0.025 stainless steel wire. A special jig (Figure 5) was prepared to hold the typodont, fixed to the universal testing machine series 8801.

Force was applied perpendicularly with a crosshead speed of 2 mm/min to push the wire in a buccolingual plane resulting in a first-order wire deflection. A metal rod attached to the moving part of the universal testing machine applied force on the wire to the palatal side at the middle of the inter bracket distance between the right central incisor and left lateral incisor, which was measured to be 14mm. The maximum loading force at a particular deflection was recorded. Results of the test were presented as the average of five replicates using new wire samples. Uncoated, Teflon coated, epoxy coated, and polyurethane coated NiTi wires were subjected to deflections of 2mm, 4mm, and 6mm.

Statistical Analysis

Data were analyzed using SPSS software version 20. The loading force of all wires was recorded in Newtons. Descriptive statistics, including means and standard deviations, were calculated for each archwire at each deflection. One-way ANOVA, followed by Tukey's post hoc test for pairwise comparisons, was used to analyze data. The level of significance was set at $P<0.05$.

Results

At 2mm deflection, epoxy-coated wires showed lower loading force followed by Teflon-coated, conventional and highest loading force was for polyurethane-coated wires, which were statistically significant. (Table 1)

Multiple pairwise comparisons at 2mm showed no significant difference in the decrease in force value for Teflon than conventional NiTi, but there is a significant difference in force values between all other possible comparisons. (Table 2)

One-way ANOVA for 4mm deflection showed the highest force values for polyurethane-coated NiTi followed by conventional NiTi, Teflon coated, and epoxy coated NiTi was statistically significant. (Table 1)

Multiple pairwise comparisons at 4mm deflection showed no difference in force values between conventional NiTi and Teflon coated NiTi, but there is a significant difference in force values between all other possible comparisons. (Table 2)

At 6mm deflection, polyurethane-coated NiTi showed the highest force values followed by conventional NiTi, Teflon coated NiTi and epoxy coated NiTi, which was statistically significant. (Table 1)

Multiple pairwise comparisons at 6mm deflection showed the difference in force values between conventional NiTi and Teflon coated NiTi, and between Teflon coated, and epoxy coated was not statistically significant. However, there is a significant difference in force between all other possible comparisons. (Table 2)

For conventional NiTi with an increase in deflection, the force was increased, which was statistically significant. (Table 1)

Multiple pairwise comparisons showed significant differences in force values for all deflection comparisons. (Table 3)

For Teflon coated NiTi wires, force increased with an increase in deflection up to 4mm later with an increase in deflection, and there was a decrease in force values, which was statistically significant. (Table 1)

Multiple pairwise comparisons for Teflon coated wires showed a significant difference in force values only between 2mm and 4mm deflection, 4mm, and 6mm. There was no significant difference in force values between the 2mm and 6mm deflection comparison. (Table 3)

For epoxy-coated NiTi wires, force increased with an increase in deflection up to 4mm later. With the increase in deflections, there was a decrease in force values, which was not statistically significant. The highest mean force value was observed at 4mm deflection. (Table 1)

Multiple pairwise comparisons for epoxy coated wires showed no significant difference in force values between any deflection comparisons. (Table 3)

For polyurethane-coated NiTi wires, force increased with an increase in deflection up to 4mm later with an increase in deflection, and there was a decrease in force values, which was statistically significant. The highest mean force value was observed at 4mm deflection. (Table 1)

Multiple pairwise comparisons for polyurethane-coated wires showed a significant difference in force values between all deflection comparisons. (Table 3)

Table 1: Mean and standard deviations of loading force of different wires at different deflections (in Newtons)

	2mm deflection	4mm deflection	6mm deflection	P- value
Group 1 (Conventional NiTi)	2.6±0.28	4.4±0.34	5.8±0.29	0.0001*
Group 2 (Teflon coated NiTi)	2.2±0.31	4.3±0.36	2.6±0.24	0.0001*
Group 3 (Epoxy coated NiTi)	0.8±0.44	1.4±0.54	1.2±0.4	0.083
Group 4 (Polyurethane coated NiTi)	4.4±0.54	8 ±0.08	6.2±0.44	0.0001*
P-value	0.0001*	0.0001*	0.0001*	

One way ANOVA; p≤0.05 considered statistically significant; * denotes statistical significance

Table 2: Multiple pairwise comparison of loading force between different wires at various deflections

		At 2mm	P-value	At 4mm	P-value	At 6mm	P-value
Group 1 (Conventional NiTi)	Group 2 (Teflon coated NiTi)	0.48	0.293	0.12	0.95	3.14	0.95
	Group 3(Epoxy coated NiTi)	1.88	0.0001*	3.02	0.001*	4.6	0.001*
	Group 4 (Polyurethane coated NiTi)	-1.72	0.0001*	-3.58	0.001*	-0.4	0.001*
Group 2(Teflon coated NiTi)	Group 3 (Epoxy coated NiTi)	1.4	0.0001*	2.9	0.001*	1.4	0.34
	Group 4 (Polyurethane coated NiTi)	-2.2	0.0001*	-3.7	0.001*	-3.5	0.001*
Group 3 (Epoxy coated NiTi)	Group 4 (Polyurethane coated NiTi)	-3.6	0.0001*	-6.6	0.001*	-5.0	0.001*

Tukey's post hoc test; p≤0.05 considered statistically significant; * denotes statistical significance

Table 3: Multiple pairwise comparison between different deflections with different wire groups

	Comparison group	Group 1 Mean difference	P-value	Group 2 Mean difference	P-value	Group 3 Mean difference	P-value	Group 4 Mean difference	P-value
2mm	4mm	-1.74	0.0001*	-2.1	0.0001*	-0.6	0.268	-3.6	0.0001*
	6mm	-3.12		-0.46	0.111	-0.4	0.597	-1.8	0.001*
4mm	6mm	-1.38		1.64	0.001*	0.2	0.92	1.8	0.001*

Tukey's post hoc test; p≤0.05 considered statistically significant; * denotes statistical significance

Discussion

The usage of esthetic orthodontic appliances has been increasing in recent times. This study evaluated three coated NiTi wires and a conventional NiTi at three (2mm, 4mm, 6mm) different deflections to test the loading forces. Loading or activation force represents force required to engage archwire into bracket slot [13]. The test was performed on a dental arch model using passive self-ligating brackets, simulating the maligned upper left central incisor's clinical condition.

For the wires to be tested within the range of their metallurgical properties, the deflection should not be more than 5% of inter-span length, which is 0.75mm for the present study [14]. Literature review reveals different wire deflections up to 5 mm; some studies have used deflections between 2 mm and 4 mm. These deflections were more than the 5% inter bracket distance, and they replicate clinical use of materials and are regularly used in clinical conditions [14-19]. The present study measured loading forces of the wires up to 6mm of deflections at 2mm, 4mm, and 6mm in this study.

At 2mm deflection, polyurethane-coated wires had the highest loading force, followed by conventional NiTi, Teflon coated NiTi, and epoxy coated wires. Other than between conventional NiTi and Teflon coated NiTi, there was a statistically significant difference in forces values between all the other wires. At 4mm deflection, all the wires exhibited similar results as at 2mm deflection. At 6mm deflection, there was a statistically significant difference in force values between all other possible comparisons except between conventional NiTi and Teflon coated NiTi and between Teflon coated and epoxy coated. Deflections up to 6mm resulted in an increase in loading force for uncoated NiTi wires. Multiple pairwise comparisons showed significant differences between any of the deflection comparisons. Coated archwires, when deflected up to 4mm, resulted in an increase in mean loading force. Increasing the deflection further, i.e., at 6mm, there was a decrease in the mean force values, which might be because of the wire's binding caused by exceeding the critical contact angle beyond 4mm deflection for coated wires.

Polyurethane-coated NiTi produced the highest force values, followed by conventional NiTi, Teflon coated NiTi and Epoxy coated NiTi. Teflon coated NiTi wires' loading force was similar to the conventional NiTi wires because of the minimal thickness of Teflon coated wires compared to epoxy coated wires. Epoxy coated wires produced lower force at all deflections than other wires, which might be due to smaller diameter NiTi inside these coated wires to compensate for epoxy coating, which is approximately 0.002 inch thick when compared to Teflon coated wires where a minimal thickness of 0.0008 to 0.001inch coating is added. Hence coating might result in the smaller inner core of NiTi in comparison with conventional NiTi archwires [1]. The results are similar to studies done by Alavi S et al. [20], Elayyan et al. [11], and Doshi UH et al. [21]' who concluded that epoxy-coated ultra-esthetic archwires and coated archwires produced lower loading and unloading forces than uncoated wires of the exact dimensions. Reduction in the inner alloy core dimensions seems to be the variable that causes more significant changes in the mechanical properties of coated archwires and variations in the materials' properties [22]. However, most of the previous studies were performed using either a three-point bending test or a free-end test. This study was designed to closely represent a maxillary arch with bonded brackets and molar tubes with a malpositioned central incisor. This study has also included newer polyurethane-coated archwires, about which very little information exists concerning the loading forces at different deflections.

From the present study, it can be deduced that conventional NiTi wires can be used for deflections up to 6mm and the coated wires up to 4mm deflection. Since the study was performed in the central incisor region, which presents an increased inter bracket distance compared to other areas in the oral cavity, the amount of deflection before binding occurs might be even less in other appliance regions because of reduced inter bracket distance.

Conclusions

1. Epoxy coated, and Teflon coated wires have shown lower loading forces compared to other wires at all deflections, which might be because of the reduced inner core of NiTi.

2. At all deflections, the highest loading force was shown by polyurethane coated wires, which might be due to an increase in thickness and stiffness of coating.

3. Coated archwires demonstrated a reduction in loading forces beyond 4mm, probably because of the archwire's binding to the bracket. Uncoated NiTi wires demonstrated an increase in loading forces up to 6mm deflections.

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