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Mechanical properties of aesthetic nickel-titanium wires before and after clinical use

Abstract. The objective of the study was to compare the mechanical properties of aesthetic orthodontic Ni-Ti wires before and after clinical use. **Materials and methods.** The experimental group consisted of 75 0.014" coated Ni-Ti wires — 15 from each of the 5 companies selected, namely Group I — D-tec, Group II — JJ Orthodontics, Group III — OSL, Group IV — American Orthodontics, and Group V — Koden. The control group consisted of two groups with 25 coated 0.014" Ni-Ti, 5 from each company (without clinical use) and 25 non-coated 0.014" Ni-Ti 5 from each company (without clinical use). The experimental wires were retrieved from the patient's mouth after one month and tested in the laboratory, for their mechanical properties which included: load deflection, flexural modulus, and microhardness. **Results.** Mean micro-hardness of experimental samples is significantly lower in Group III (303.9±8.9; *p*=0.001). The mean micro-hardness of coated control samples is significantly lower in Group I (309.8±18.2; *p*=0.674). In Groups I, II, IV and V, the mean micro-hardness of experimental, coated and non-coated control samples was not statistically significant. **Conclusion.** On comparison of mechanical properties like load deflection, flexural modulus, and hardness of aesthetic orthodontic Ni-Ti wires, it was observed that there was a significant difference among five different types of Ni-Ti wire. Also, difference was observed among the experimental group, the coated control group and the non-coated control group. A significant difference was seen in Ni-Ti wire before and after clinical use.

Key words: aesthetic wires, mechanical properties, Ni-Ti wires

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Механические свойства эстетических никель-титановых дуг до и после клинического применения

Реферат. Цель исследования — сравнение механических свойств эстетических ортодонтических никель-титановых дуг до и после клинического применения. **Материалы и методы.** Экспериментальная группа состояла из 75 никель-титановых дуг с покрытием 0,014" — по 15 от каждой из 5 выбранных компаний: I группа — D-tec, II группа — JJ Orthodontics, III группа — OSL, IV группа — American Orthodontics и V группа — Koden. Контрольная группа состояла из двух групп: контрольная 1 — 25 0,014" Ni-Ti дуг с покрытием, по 5 от каждой компании (без клинического использования) и контрольная 2 — 25 не покрытых 0,014 Ni-Ti дуг, по 5 от каждой компании (без клинического использования). Экспериментальные дуги были извлечены из полости рта пациента через 1 месяц и протестированы в лаборатории на механические свойства, которые включали отклонение под нагрузкой, модуль упругости и микротвердость. **Результаты.** Средняя микротвердость экспериментальных образцов значительно ниже в III группе (303,9±8,9; *p*=0,001). Средняя микротвердость контрольных образцов с покрытием значительно ниже в I группе (309,8±18,2; *p*=0,674). В I, II, IV и V группах средняя микротвердость опытных образцов, контрольных образцов с покрытием и без него не была статистически значимой. **Заключение.** При сравнении механических свойств, таких как прогиб под нагрузкой, модуль упругости и твердость эстетических ортодонтических Ni-Ti-дуг, было отмечено, что существует значительная разница между пятью различными типами Ni-Ti-дуг. Также наблюдалась разница между экспериментальной группой, контрольной группой с покрытием и контрольной группой без покрытия. Значительная разница наблюдалась в Ni-Ti-дуге до и после клинического применения.

Ключевые слова: эстетическая дуга, механические свойства, Ni-Ti дуга

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INTRODUCTION

The demand for more aesthetic orthodontic treatment modalities is growing. This trend is understandable since patients hope for improved appearance and the number of adult patients is increasing [1]. Currently, aesthetic brackets have become an inescapable reality of the orthodontic clinic, offering an alternative to metal brackets. However, the same is not true of aesthetic wires, which were seldom reported in the orthodontic literature until the mid-2000s.2 Metallic arch wires coated with coloured polymers or inorganic materials are currently the solution to this esthetic problem [2]. Materials used in coating are polymers such as synthetic fluorine-containing resin or epoxy resin composed mainly of polytetrafluoroethylene, which is used to simulate tooth colour [3].

The mechanical properties of metallic arch wires could be affected during this process and by possible changes in their inner alloy core dimensions to compensate for the thickness of the coating layer [4, 5]. It has been reported that coating may or may not increase unloading forces and surface roughness of as received wires, depending on the technique used for surface treatment [6, 7]. Loss of a significant amount of coating, poor colour stability, change of mechanical behaviour and force values, and increase in surface roughness, have all been reported after clinical use [8, 9].

Furthermore, several different manufacturing companies provide these coated wires. Some of these wires are already used in various studies [10—12].

This study is an effort towards studying and comparing mechanical properties like load deflection, flexural modulus and hardness of of aesthetic orthodontic Ni-Ti wires before and after clinical use.

MATERIALS AND METHODS

The experimental samples included 75 coated and 25 non-coated 0.014" Ni-Ti wires (10 and 5 from each of the 5 companies) namely:

1) D-Tec (Sweden) — Group I;
2) JJ Orthodontics (India) — Group II;
3) OSL (United Kingdom) — Group III;
4) American Orthodontics (USA) — Group IV;
5) Koden (India) — Group V.

Fifty subjects were randomly selected for orthodontic treatment. One coated 0.14" Ni-Ti wire per subject was placed in 50 different subjects in the upper arch only. The wires were retrieved from the patient's mouth after one month and tested in the PRAJ Metallurgical Laboratory (Pune, India), for their mechanical properties which included, flexural modulus, modulus of elasticity and load deflection.

The control group consisted of 25 coated 0.014" Ni-Ti, five from each company (without clinical use) and 25 non-coated 0.014" Ni-Ti five from each company (without clinical use). The coated wires from the experimental groups were placed in the subject's mouth (one wire per subject) for a period of one month as a part of the initial levelling and aligning procedure of fixed mechanotherapy.

The mechanical properties that were evaluated and compared included flexural modulus, modulus of elasticity, hardness, and load deflection. Flexural modulus was evaluated using a Universal testing machine. Three-point bending test for the evaluation of the load-deflection and flexural modulus of the wires before and after clinical use of the samples. The hardness of the coated wire was then measured before and after clinical use on the Reichert micro-hardness tester.

In the statistical processing of the data, all hypotheses were formulated using a one-way analysis of variance (ANOVA) with a post-hoc Bonferroni correction for multiple comparisons between groups, $p<0.05$ was considered statistically significant.

RESULTS

In the present study, the load-deflection properties and flexural modulus were evaluated using a Universal testing machine. The load-deflection curve generated was analyzed to detect the mechanical properties of the wires. The mean load at 1 mm and 2 mm of experimental samples is significantly higher in Group II ($p<0.05$; table 1 and 2). The mean load of coated control samples is significantly higher in Group V ($p<0.05$). The mean load of non-coated control samples is significantly higher in Group III ($p<0.05$). In Groups I and V, the mean load at 1 mm deflection of experimental samples differs significantly compared to coated control samples ($p<0.05$). In Groups II and V, the mean load at 1 mm deflection of experimental samples differs significantly compared to coated control samples ($p<0.05$).

Table 1. Mean load experience at 1 mm deflection (N)

	Group I (*n*=20)	Group II (*n*=20)	Group III (*n*=20)	Group IV (*n*=20)	Group V (*n*=20)
Experimental Sample	1.50±0.32	2.03±0.20*#	1.68±0.50	1.66±0.28	1.64±0.37
Coated control	1.92±0.18#	1.43±0.11	1.96±0.07	1.45±0.13	2.54±0.12*#
Non-Coated Control	1.49±0.23	1.60±0.16	1.98±0.19	1.56±0.28	1.29±0.26

*Remark. The difference is statistically significant (p<0.05): * Differs from other samples in series; # Differs from experimental samples in group.*

Table 2. Mean load experience at 2 mm deflection (N)

	Group I (*n*=20)	Group II (*n*=20)	Group III (*n*=20)	Group IV (*n*=20)	Group V (*n*=20)
Experimental Sample	1.94±0.49	2.62±0.26*	2.22±0.67	2.22±0.43	2.22±0.55
Coated control	2.48±0.13	2.14±0.09	2.77±0.15	2.15±0.18	3.41±0.19*
Non-Coated Control	1.82±0.20	2.07±0.16	2.66±0.14	2.11±0.37	1.54±0.22

*Remark. The difference is statistically significant (p<0.05): * Differs from other samples in series; # Differs from experimental samples in group.*

The mean flexural modulus of experimental samples is significantly higher in Group V — 167—216 GPa ($p<0.05$; table 3). The mean flexural modulus of coated control samples is significantly higher in Group V (220—244 GPa; $p<0.05$). The mean flexural modulus of non-coated control samples is significantly higher in Group III (159—197 GPa). In Groups I, II and IV the mean flexural modulus of experimental samples is significantly higher compared to non-coated control samples ($p<0.05$). In Group V, the mean flexural modulus of coated control samples is significantly higher compared to the non-coated control sample ($p<0.05$).

For hardness, near-straight portions of the wires were embedded into acrylic blocks and polished. The acrylic blocks were then placed on the Reichert hardness tester and various indentations using a diamond tip (Berkovich indenter) were made on the samples. On inter-group comparison, the mean micro-hardness of experimental samples is significantly lower in Group III ($p<0.05$; table 4). The mean micro-hardness of coated control samples is significantly lower in Group I ($p<0.05$). In Groups III, IV and V, the mean micro-hardness of experimental samples is significantly lower compared to coated and non-coated control samples ($p<0.05$).

DISCUSSION

This study provides crucial information regarding the mechanical properties of coated orthodontic Ni-Ti wires and whether clinical use and the esthetic coating process affect their properties and if so, to what extent. Hence, this study also compares the differences in their mechanical properties with their unused and non-coated counterparts.

The present study has comprehensively studied the mechanical properties like flexural modulus, load deflection properties, micro-hardness and surface coating properties of these coated orthodontic Ni-Ti wires of 0.014" diameter, after clinical use and compared them with their non-coated and coated counterparts which were not used clinically. The test set-up was chosen from the many available in the literature as one that would emulate the complexity as seen in the study by Bradley et al. (2013) [8]. The use of an agreed-upon standard allows for replication and comparison of studies and can provide a more efficient way to test new wires developed by manufacturers.

In the present study, the load-deflection properties and flexural modulus were evaluated using a Universal testing machine. Measurement of the force (N) at loading and unloading extensions was able to give insight into the tooth-moving properties of various wires. This suggests that coated wires showed more amount of force values at various deflections than their used and non-coated counterparts. The study results agree with Nakano et. al. (1999) [13]. The unloading forces generated at 1mm deflection were lower in the experimental wires as compared to the as-received coated control 1 wire. These findings are in accordance with the findings of Elayyan et al., (2008) where the retrieved coated arch wires generated lower unloading forces (15—29 g) when deflected for 1 mm and 2 mm compared with as-received coated arch wires (46—59 g) which were statistically significant ($p<0.001$) [14].

The flexural modulus of each wire was evaluated using the stress-to-strain curve. In the present study, the load-deflection properties as well as the flexural properties do not show much statistical significance in either the coated or non-coated control samples which suggests that the stiffness of the wires is almost the same in coated as well as non-coated wires although the forces delivered by the coated wires do seem to be higher than their non-coated counterparts. This is in discordance with the previous studies. This could be attributed to the newer techniques developed by the manufacturers which they do not share, lest they relinquish the edge over their competitors.

In the present study, Berkovich's diamond tip was used for indentation like the studies and values were evaluated according to the Vickers hardness scale and the software ISO 1501:2002, ISO 6507-1:1997 was used to chart and classify the values obtained. This variation could arise because of the coating process. However, the coating methodology and the exact process of manufacturing are not disclosed by most of the manufacturers.

This study was limited only by the lack of information available from manufacturers regarding their manufacturing process. Once again there is no standard in the manufacture and several factors including but not limited to austenite finish temperatures, temperatures used during coating application, actual thickness of coatings and exact composition of the coating, limit a true understanding of these wires.

Table 3. Mean value of flexural modulus (GPa)

	Group I (*n*=20)	Group II (*n*=20)	Group III (*n*=20)	Group IV (*n*=20)	Group V (*n*=20)
Experimental Sample	183.6±33.2	182.4±22.7	151.9±31.1	146.7±26.3	191.1±24.6*
Coated control	166.0±16.4	125.0±10.9	170.8±12.7	143.8±12.7	231.8±11.8*
Non-Coated Control	132.2±14.9#	139.0±11.4#	178.0±18.9*	149.0±12.1#	126.8±19.7

*Remark. The difference is statistically significant (p<0.05): * Differs from other samples in series; # Differs from experimental samples in group.*

Table 4. Mean value of micro hardness test (HV)

	Group I (*n*=20)	Group II (*n*=20)	Group III (*n*=20)	Group IV (*n*=20)	Group V (*n*=20)
Experimental Sample	318.6±10.1	320.7±15.6	303.9±8.9*#	323.1±9.0#	318.5±9.3#
Coated control	309.8±18.2*	339.9±13.2	340.7±7.9	332.0±5.8	336.4±7.0
Non-Coated Control	336.8±11.4	325.4±10.4	341.7±15.9	340.1±11.4	336.8±9.6

*Remark. The difference is statistically significant (p<0.05): * Differs from other samples in series; # Differs from experimental samples in group.*

CONCLUSION

On comparison of mechanical properties like load deflection, flexural modulus, hardness and surface coating of aesthetic orthodontic Ni-Ti wires, it was observed that there was a significant difference among five different types of Ni-Ti wire. Also, difference was observed among the experimental group, the coated control group and the non-coated control group. A significant difference was seen in Ni-Ti wire before and after clinical use. This study directly relates to the clinician practicing evidence-based dentistry. It provides not only a specific guide of which round 0.014" coated wires perform similarly to their non-coated counterpart but also begins to explain the future selection of these coated arch wires. There are an infinite myriad of iterations and it is not the scope of this dissertation to discuss each one in detail or to dictate treatment mechanics; however, it can be used as a guide for clinical decision-making.

Conflict of interests. The authors declare no conflict of interests.

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