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Mechanical Properties and Clinical Performance of Different Brands of Nickel Titanium Archwires Following Intraoral Use: A Prospective Clinical Trial

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***Abstract*---**Background: Superelastic NiTi wires may experience change in performance when placed intraorally. Objectives: To evaluate the effect of intraoral use of three brands of nickel titanium archwires on their mechanical properties and crowding relief ability. Methods: Three groups (n=39) of 0.016″ round NiTi archwires: Dentaurum (A), American Orthodontics (B) and IMD Orthodontics (C) were subdivided according to the intervention (n=13) into: As-received, no intervention (subgroup 1), *in-vivo* (subgroup 2), and *in-vitro* (subgroup 3). Plateau slope, resilience, and elastic modulus of all wires were tested using a universal testing machine. The relief of crowding following intraoral use for 8 weeks was assessed using Little's irregularity index. Results were significant at $p \leq 0.05$. Results: For all NiTi brands, the highest plateau slope value; among the subgroups, was recorded following the intraoral use (*in-vivo*). For the

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in-vivo wires (subgroup 2), the Dentaurum wires revealed the lowest plateau slope value (0.258 N/mm ± 0.032) while the IMD wires revealed the lowest resilience values (36.24 $J.mm^{-3}$ ± 0.6). Within each subgroup, there was no significant difference in the modulus of elasticity of wires between the different wires. The Little's irregularity index decreased over time, and the difference between the groups was not significant. No significant difference existed between the groups in terms of inter-canine width. Conclusion: Dentaurum wire may seem to deliver light, continuous, and constant forces following intraoral use compared to the other brands. Despite the change in mechanical properties that took place in all three wire brands following intraoral use, their clinical performance was not impaired.

***Keywords*---**Nickel Titanium, plateau slope, Dentaurum, American orthodontic, IMD orthodontic.

Introduction

Nickel titanium (NiTi) archwires are used for initial alignment of malocclusion owing to their shape memory and superelastic properties. Superelastic NiTi archwires are characterized by a load-deflection curve with a plateau during unloading. Since deflected superelastic archwires behave elastically for weeks to months, constant force is transmitted to the teeth over long activation periods, resulting in a desirable biologic response. However, the different commercially available superelastic NiTi wires may possess different properties depending on their manufacturing process (1). Furthermore, the mechanical properties of archwires are directly affected by oral environmental factors such as extreme pH and temperature variations, complex oral flora, and salivary enzymes (2). These factors may impact the amount of force delivered by the archwire over time. Insufficient data regarding the mechanical and clinical performance of such wires makes it difficult for orthodontists to choose the most adequate material with the best cost-benefit ratio. To the best of our knowledge, there is not enough literature discussing the influence of the oral environment on the mechanical properties of NiTi archwires. Therefore, the current study aimed to evaluate the mechanical properties of three widely used 0.016-inch Nickel Titanium archwire brands following their exposure to the oral environment. Furthermore, the effectiveness of these wires in relieving crowding over time was investigated. The null hypothesis was that there will be no significant difference in the mechanical properties of the three brands of Nickel Titanium archwires after exposure to the oral environment following clinical use.

Materials and Methods

Sample size calculation

Sample size calculation was performed using G*Power Version 3.1.9.2 (3). Based on the results of Lombardo *et al.,* (2019) (2); 12 subjects per group were considered sufficient to achieve a power of a study 80 % and alpha (α) level of

(5%). Sample size was increased to 13 subjects per group to compensate for a drop-out rate of 10% after 8 weeks. Accordingly, a total of 117 wires of 0.016″ round NiTi archwires were divided into three groups (n=39) based on the wire brand: Group A (Rematitan Lite®, Dentaurum), Group B (NT3® SE NiTi Wire American Orthodontics), and Group C (IMD® Orthoshape Superelastic wires, IMD Orthodontics). Each group was further subdivided into three subgroups (n=13) according to the intervention: Subgroup 1 (as-received), the wires were measured as-received from the manufacturer i.e. no intervention (negative control group), Subgroup 2 (*in-vivo*), the wires were used intraorally for 8 weeks for initial leveling and alignment, and Subgroup 3 (*in-vitro*), the as-received wires immersed in artificial saliva for 8 weeks (positive control group). Artificial saliva was prepared following the method reported by Sri *et al.,* (2015) (4). Briefly, albumin, cellulose, potassium chloride, potassium phosphate, and sodium fluoride were dissolved in water. Methyl paraben, magnesium chloride and dextrose were dissolved in warm water and then cooled down before mixing all the solutions together. The as-received wires were immersed in artificial saliva for 8 weeks. During this immersion period, the artificial saliva was replaced twice with a fresh mix i.e. once every 4 weeks.

Patient selection

After approval of the Research ethics committee (code (26)/11-2020), thirty-nine 18- to 24-year-old patients having moderate upper arch crowding with similar gross malocclusion were selected from the orthodontics outpatient clinic. There was no significant difference in mean age values, gender distributions and occlusion classes between the three groups. The treatment procedures, aim of the study, possible side effects, and treatment alternatives were thoroughly explained to all the participants. The subjects received a SWA; Roth prescription slot 0.022 x 0.028 mil. The molar tubes and brackets were bonded to the tooth surface using orthodontic light cured composite resin (Light Bond Medium Push Syringe Kit Non-Fluoride, Reliance). Participants were randomly assigned into one of three groups using Microsoft Office Excel 2013 sheet. The 0.016″ NiTi wire was ligated by o-ties using a figure eight configuration (T_0). In order to eliminate any bias, the present study was a double-blinded clinical trial, where neither the operator nor the outcome assessor knew the brand of the 0.016″ round NiTi archwire used. The patients were asked to come back for the follow up visit after 4 weeks (T_1) to change the elastomeric ligature, followed by a second follow up visit after 8 weeks (T_2) to retrieve the NiTi wires (*in-vivo* subgroup) to test their mechanical properties.

Mechanical testing

All wires were sectioned and immersed in a 37°C water bath one minute prior to mechanical testing to simulate the clinical conditions. The water bath temperature was monitored using a thermocouple and maintained using a portable water heating coil. The plateau slope, resilience, and elastic modulus of all wires were evaluated via three-point bending test using an Instron universal testing machine (Model 4301, Instron Corp, Canton, Mass). The test was conducted in accordance with the ISO 15841 specification for orthodontic wires with the exception that the bottom support span was 14 mm rather than 10 mm due to fixture limitations (ISO, 2014). The wires were mounted on four non-self-ligating brackets (0.022 Edgewise standard, American orthodontics) using elastomeric ligatures tied in figure 8. The brackets were glued to an acrylic resin base to create a 14-mm span between the internal sides of two adjacent brackets. The stage was attached to the upper movable head of the Instron machine. A single pole, fixed to a stage, was attached to the lower head of machine in such a manner that the tip of the pole was at the center of the wire span (5). The force applied was regulated by an Instron 4467 dynamometer connected to a 100-N load cell. The mid-portion of the wire was deflected one mm with a crosshead speed of one mm/minute and a full-scale load of 100-N (Figure 1).

a) b)

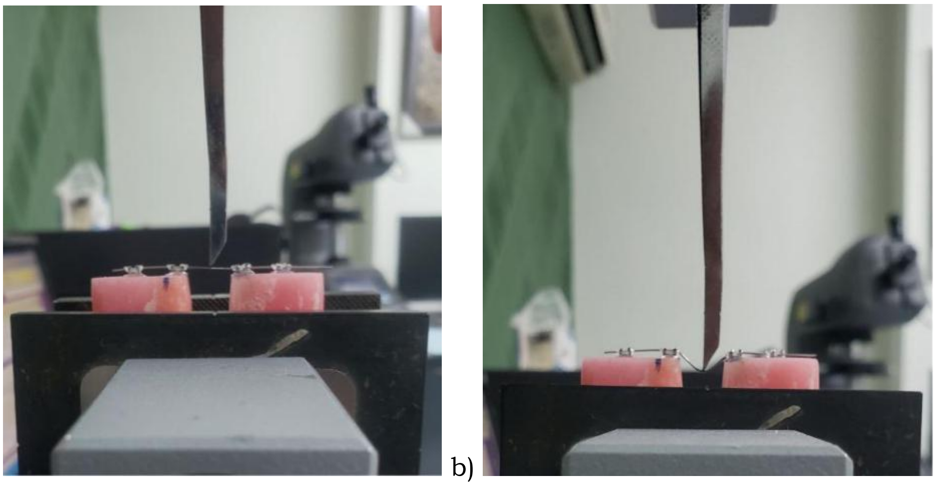

Figure 1: Three-point transverse bending setup of the archwire in the Instron universal testing machine for the load deflection measurement; a) before loading b) during loading.

The center of each segment was deflected to 3.1 mm of deflection as recommended by the ISO14841:2006. The wires were unloaded at the same speed until the force reached zero. The plateau slope was calculated from the plotted load-deflection curves obtained for each wire. From the unloading curve, the deflection at the end of the plateau, and the forces (F) delivered at that point, and at 3-, 2-, 1- and 0.5-mm deflection were recorded. A computer software program was used to record the Load (N) and deflections (mm) for each specimen. The plateau slope ($\text{Slope}_{\text{3mm}}$), expressed in N/mm, between 3 mm and S_p of deflection, was calculated using the following equation (6):

$$\text{Slope}_{\text{3mm}} = \frac{(F_{\text{def 3mm}} - F_p)}{(3 - S_p)}$$

where F_p is the minimum force level (N) at the end of the plateau (Figure 2) and S_p is the deflection (mm) of the archwire at the end of plateau.

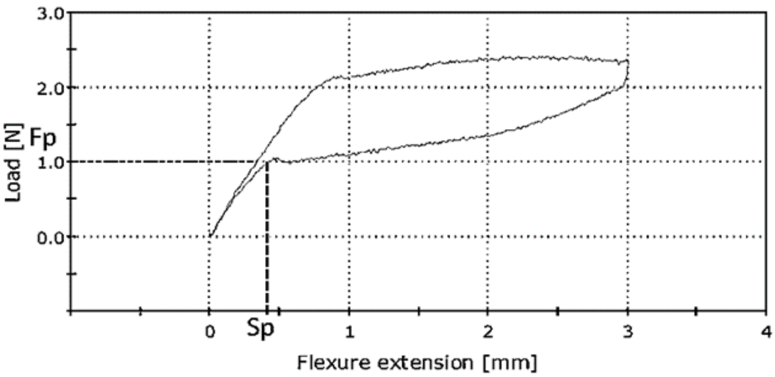

Figure 2: A schematic illustration of a loading/unloading curve of a NiTi archwire showing the F_p and the S_p points used for the calculation of the plateau slope

The obtained load/deflection data were plotted and the linear slope of the deactivation curve was recorded. The deactivation modulus (E) in MPa, was calculated using the following equation (7):

$$E = \frac{PL^3}{4BH^3e}$$

where P is the load (N), L is wire length (mm), B is wire width, H is wire height, and e is the deflection (mm). Resilience was measured by the modulus of resilience and was expressed as the amount of elastic strain energy per unit volume ($J.mm^{-3}$) (7). Permanent deformation of the wires was examined using Stereomicroscope through photographing the wire before bonding (T_0) and after 8 weeks (T_2) (8).

Calculation of the degree of crowding resolution "Little's irregularity index"

In order to calculate the relief of crowding that occurred following intraoral use of the wires; subgroup 2 wires (*in-vivo*), upper arch impressions were taken for all the patients before wire placement (T_0) and after 8 weeks of intraoral use (T_2). Impressions were poured immediately to avoid any distortion. The models were then scanned with 3Shape TRIOS to record digital orthodontic models. A 3D image was produced on the monitor and STL file was generated for each patient. The primary clinical outcome: alignment efficiency, was calculated using Little's irregularity index (LII) by two assessors twice for each patient. The assessors were blinded as to which wire was used in each patient. The degree of resolution of crowding was measured in mm using Ortho Analyzer 3shape program software for digital models (Figure 3) where the linear displacement of the anatomic contact points was measured from the mesial of the left maxillary canine to the mesial of the right maxillary canine and an additional measurement from the mesial of the left maxillary first molar to the mesial of the right maxillary first molar (9). Also, the arch widths (inter-canine and inter-molar) were evaluated as secondary outcome measures. Canine measurements were made from cusp tip to cusp tip, and molar measurements were made from central fossa to central fossa.

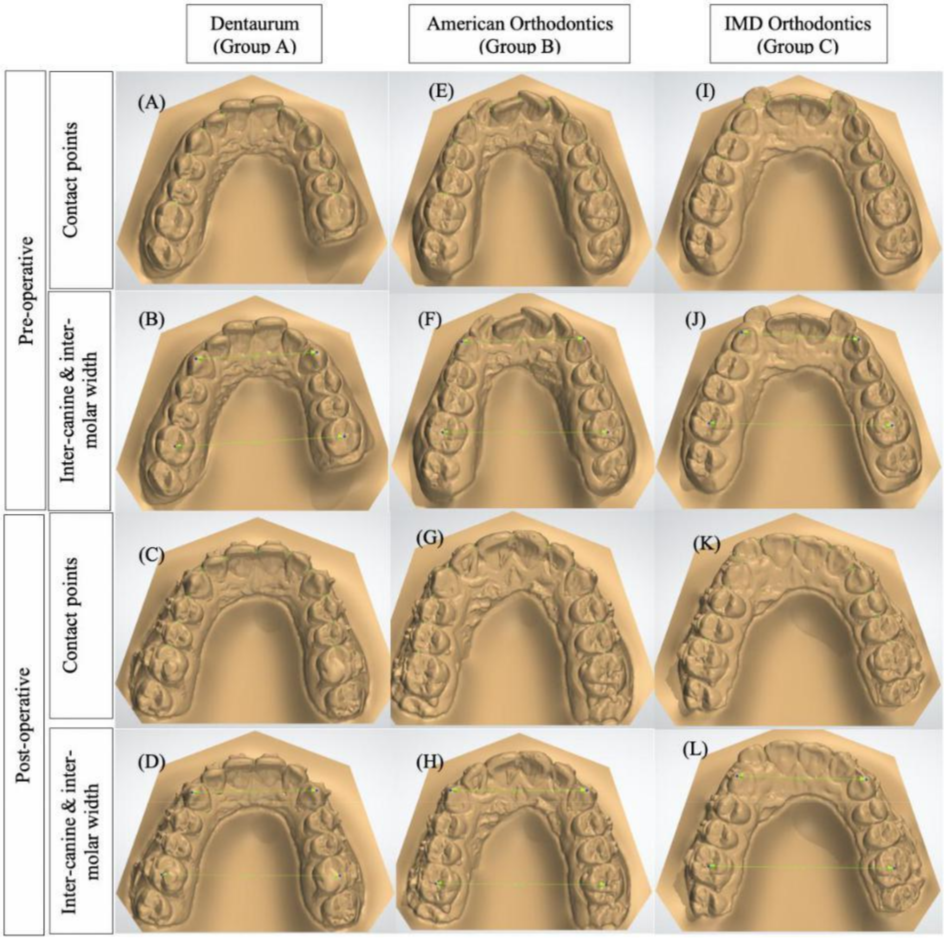

Figure 3: 3D images of upper arch model. Figures A-D represent the Dentaurum wire group: (A) preoperative contact points, (B) preoperative inter-canine & inter-molar width, (C) postoperative contact points and (D) postoperative inter-canine & inter-molar width. Figures E-H represent the American Orthodontic wire group: (E) contact points, (F) preoperative inter-canine & inter-molar width, (G) postoperative contact points and (H) postoperative inter-canine & inter-molar width. Figures I-K represent the IMD orthodontic wire group: (I) preoperative contact points, (J) preoperative inter-canine & inter-molar width, (K) postoperative contact points and (L) postoperative inter-canine & inter-molar width

Statistical analysis

Numerical data were explored for normality using Kolmogorov-Smirnov and Shapiro-Wilk tests of normality. For parametric data, results were listed as means and standard deviations (SD). Repeated measures Analysis of Variance (ANOVA) was used to compare between the groups as well as to study the changes within each group. Bonferroni's post-hoc test was used for pair-wise comparisons when the results of the ANOVA test were significant. The significance level was set at $p \leq 0.05$. Statistical analysis was performed with IBM SPSS Statistics for Windows, Version 23.0. Armonk, NY: IBM Corp.

Results

Results of the Mechanical testing

Representative load deflection curves from which the plateau slope was obtained are shown in Figure 4.

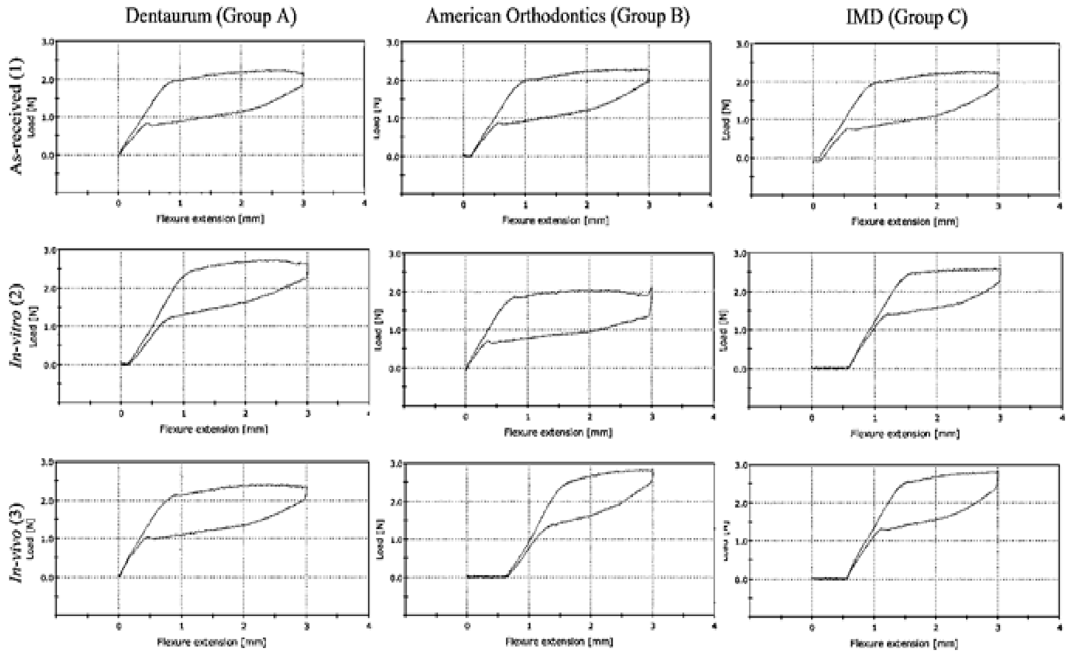

Figure 4: The load-deflection curves for all wire subgroups

The results of the plateau slope (N/mm), resilience (J.mm^{-3}), and the elastic modulus (MPa) of each subgroup of wire: Subgroup 1 (as-received), subgroup 2 (*in-vivo*), and subgroup 3 (*in-vitro*), and the results of repeated measures ANOVA test for comparison between the different wire groups: Group A (Dentaurum wires), Group B (American Orthodontics wires) and group C (IMD wires) within each condition are shown in Table 1. For the as-received wires (subgroups 1), the IMD wires (Group C) had the highest plateau slope (0.314 N/mm ± 0.041) whereas the American Orthodontics wires (Group B) had the highest resilience. On the other hand, the results of the *in-vitro* wires (subgroups 3) revealed that IMD wires (Group C) had the highest plateau slope and the lowest resilience compared to both Groups A and B. As for the *in-vivo* wires (subgroups 2), the Dentaurum wires (Group A) revealed the lowest plateau slope value (0.258 N/mm ± 0.032) while the IMD wires (Group C) revealed the lowest resilience values. Regarding the modulus of elasticity, no significant difference existed between the tested groups of wires in each of the 3 subgroups.

Table 1: The mean, standard deviation (SD) values of the plateau slope (N/mm), resilience values ($J.mm^{-3}$) and the modulus of elasticity values (MPa), and the results of repeated measures ANOVA test for comparison between the wire groups at the different conditions.

		Dentaurum (Group A)		American orthodontics (Group B)		IMD (Group C)		*P*-value
		Mean**	SD	Mean**	SD	Mean**	SD	
As-received (Subgroup 1)	Plateau Slope (N/mm)	0.255 ^{B}	0.032	0.255 ^{B}	0.032	0.314 ^{A}	0.041	<0.001*
	Resilience ($J.mm^{-3}$)	37.44 ^{B}	0.50	38.49 ^{A}	0.64	37.16 ^{B}	0.62	<0.001*
	Modulus of Elasticity (MPa)	36.79	5.11	40.74	5.75	37.64	5.31	0.160
In-vivo (Subgroup 2)	Plateau Slope (N/mm)	0.258 ^{B}	0.032	0.309 ^{A}	0.039	0.321 ^{A}	0.041	<0.001*
	Resilience ($J.mm^{-3}$)	37.55 ^{A}	0.63	37.73 ^{A}	0.63	36.24 ^{B}	0.60	<0.001*
	Modulus of Elasticity (MPa)	34.96	4.94	38.33	5.41	36.51	5.15	0.263
In-vitro (Subgroup 3)	Plateau Slope (N/mm)	0.255 ^{B}	0.033	0.281 ^{B}	0.036	0.315 ^{A}	0.040	<0.001*
	Resilience ($J.mm^{-3}$)	38.12 ^{A}	0.64	38.11 ^{A}	0.64	36.6 ^{B}	0.61	<0.001*
	Modulus of Elasticity (MPa)	36.04	5.09	39.51	5.58	36.96	5.21	0.236

**: Significant at $P \leq 0.05$, Different superscripts in the same row indicate statistically significant difference*
***: Mean of 13 specimens*

The results of the plateau slope (N/mm), resilience ($J.mm^{-3}$), and the elastic modulus (MPa) of the tested wires: Group A (Dentaurum wires), Group B (American Orthodontics wires) and group C (IMD wires) and the results of repeated measures ANOVA test for comparison between the different subgroups: Subgroup 1 (as-received), subgroup 2 (*in-vivo*), and subgroup 3 (*in-vitro*) within each wire are shown in *Table 2*. In case of Dentaurum wires (Group A), the highest plateau slope (0.258 N/mm ± 0.032) as well as the lowest modulus of elasticity were evident in the *in-vivo* subgroup (34.96 MPa ± 4.94) whereas the highest resilience (38.12 $J.mm^{-3}$ ± 0.64) was revealed in the *in-vitro* subgroup. Regarding the American Orthodontics wires (Group B), the *in-vitro* subgroup had a plateau slope value that was significantly higher than that of the as-received subgroup and lower than that of the *in-vivo* subgroup. On the contrary, the resilience values of the *in-vitro* subgroups were higher than those of *in-vivo* subgroup and lower than those of the as-received subgroup. The lowest modulus of elasticity was revealed in the *in-vivo* group (38.33 MPa ± 5.41) compared to both the as-received and *in-vitro* subgroups. For IMD wires (Group C), both the highest plateau slope (0.321 N/mm ± 0.041) and the lowest resilience (36.24 $J.mm^{-3}$ ± 0.60) were evident in the *in-vivo* subgroup whereas the highest modulus of elasticity (37.64 MPa ± 5.31) was evident in the as-received subgroup. On the other hand, the resilience of the *in-vitro* subgroup (36.6 $J.mm^{-3}$ ± 0.61) was significantly lower than that of the *in-vivo* subgroup and higher than that of the as-received subgroup.

Table 2: The mean, standard deviation (SD) values of the plateau slope (N/mm), resilience ($J.mm^{-3}$), and the elastic modulus (MPa) of each of the tested wire groups: Group A (Dentaurum wires), Group B (American Orthodontics wires) and group C (IMD wires), and the results of repeated measures ANOVA test for comparison between the different subgroups: Subgroup 1 (*as-received*), subgroup 2 (*in-vivo*), and subgroup 3 (*in-vitro*) within each wire.

	Wire type	Subgroup 1 (As-received)		Subgroup 2 (*In-vivo*)		Subgroup 3 (*In-vitro*)		*P*-value
		Mean**	SD	Mean**	SD	Mean**	SD	
Plateau Slope (N/mm)	Dentaurum	0.255 ^{B}	0.032	0.258 ^{A}	0.032	0.255 ^{B}	0.033	<0.001*
	American Orthodontics	0.255 ^{C}	0.032	0.309 ^{A}	0.039	0.281 ^{B}	0.036	<0.001*
	IMD Orthodontics	0.314 ^{B}	0.041	0.321 ^{A}	0.041	0.315 ^{B}	0.040	<0.001*
Resilience ($J.mm^{-3}$)	Dentaurum	37.44 ^{B}	0.50	37.55 ^{B}	0.63	38.12 ^{A}	0.64	<0.001*
	American Orthodontics	38.49 ^{A}	0.64	37.73 ^{C}	0.63	38.11 ^{B}	0.64	<0.001*
	IMD Orthodontics	37.16 ^{A}	0.62	36.24 ^{C}	0.60	36.6 ^{B}	0.61	<0.001*
Modulus of Elasticity (MPa)	Dentaurum	36.79 ^{A}	5.11	34.96 ^{B}	4.94	36.04 ^{A}	5.09	<0.001*
	American Orthodontics	40.74 ^{A}	5.75	38.33 ^{B}	5.41	39.51 ^{A}	5.58	<0.001*
	IMD Orthodontics	37.64 ^{A}	5.31	36.51 ^{B}	5.15	36.96 ^{B}	5.21	<0.001*

**: Significant at $P \le 0.05$, Different superscripts in the same row indicate statistically significant difference*

***: Mean of 13 specimens*

The comparison of pre- and post-operative stereomicroscopic photographs of the different wires revealed no signs of permanent deformation, (Figure 5). Striations parallel to the long axis of the wires, which may be characteristic for the manufacturing process, were noticed on the surface of the as-received archwires.

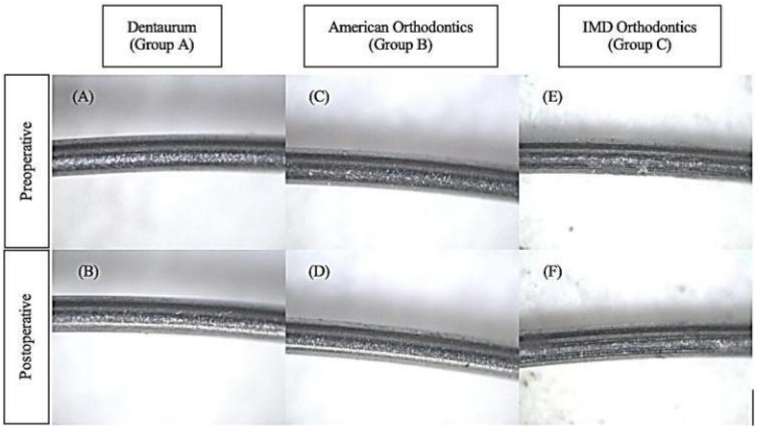

Figure 5: Stereo microscope images (50x magnification) of wires from Dentaurum wire (A) preoperatively (as-received subgroup), (B) post-operatively (*in-vivo* subgroup), American Orthodontic wire (C) preoperatively (D) postoperatively and IMD Orthodontic wire (E) preoperatively (F) postoperatively.

Results of the resolution of crowding "Little's irregularity index testing"

All wire types revealed a significant decrease in the Little's irregularity index over time (*p*-value <0.001). Regarding the inter-canine width, whether at T0 or T_2; no significant difference existed between wire types (P-value = 0.290, 0.296, respectively). As for the inter-molar width, whether at T_0 or T_2, American orthodontics had a smaller mean width than that of Dentaurum and IMD orthodontics wires, (Table 3).

Table 3: The mean, standard deviation (SD) values of the inter-canine and inter-molar width values (mm) and the results of repeated measures ANOVA test for comparison between the different wire types.

	Time	American Orthodontics		Dentaurum		IMD Orthodontics		*P*-value
		Mean**	SD	Mean**	SD	Mean**	SD	
Inter-canine	T_0	34.69	1.04	35.39	1.25	35.43	1.6	0.290
	T_2	34.93	1.01	35.64	1.22	35.64	1.63	0.296
Inter-molar	T_0	46.19 ^{B}	0.86	47.85 ^{A}	1.15	47.82 ^{A}	1.23	<0.001*
	T_2	46.44 ^{B}	0.84	47.99 ^{A}	1.17	47.68 ^{A}	1.28	0.002*

** Significant at P ≤ 0.05, Different superscripts in the same row indicate statistically significant difference. **: Mean of 13 specimens*
T_0: preoperative T_2: postoperative

Discussion

To date, Nickel titanium (NiTi) orthodontic archwires remain the most commonly used leveling and aligning wires. Once deflected, irrespective of the degree of deflection, nickel titanium archwires behave as superelastic i.e. they deliver constant forces to the teeth over a long activation period. Hence, they result in a desirable biologic response (1). Since several brands of NiTi wires are commercially available in the market, this study aimed to compare the mechanical and clinical performance of three commercially available brands of nickel titanium archwires. The three wire brands selected in this study; Dentaurum, American Orthodontics and IMD Orthodontics, are among the most commonly used commercially available brands in the field of orthodontics. Each group of wires was subdivided into as-received (negative control), *in-vivo* wires, placed intraorally for 8 weeks, and *in-vitro*: as-received wires immersed in artificial saliva for 8 weeks (positive control group). The artificial saliva group was included in this study to rule out any individual variation in patient oral hygiene, temperature fluctuations and mechanical forces during mastication. The design of the current study was a prospective study. Prospective studies are preferred since they provide results with fewer potential sources of bias and confounding compared to retrospective studies (10). This clinical trial was conducted for a duration of 8 weeks (11) since this is usually the maximum duration for a wire to be placed intraorally. The wires used in each group were from different batches in order to eliminate any batch discrepancy.

Amaya *et al.,* (2020) (12), reported that after 3 months of clinical usage, wires experienced reduction in their mechanical properties and showed less resistance to breakage. Therefore, mechanical evaluation of orthodontic archwires seemed of utmost importance in understanding their behavior during clinical use. The three-point bending test was used in the current study since it was reported as the most appropriate method for obtaining load-deflection results *in-vitro* (13). In the current study, only the straight end of the wires (posterior segments) was used to avoid the influence of possible differences in shape of the curved (anterior) region, which could lead to increased levels of stress as the wires were tested (14). As the activated archwire tends to return to its original position, the tooth movement constitutes the unloading force. Thus, the leveling and aligning force is not the activation force but rather the deactivation or unloading force of the wire. On a load-deflection curve, the unloading plateau is characterized by a horizontal region where a constant force is exerted over a particular range of tooth movement. The closer the slope value is to zero, the more constant the force is (15). From a clinical perspective, such unloading plateau denotes that the wire will apply a light, continuous force to the teeth even though the teeth are moving, and the deflection of the wire is decreasing significantly (16). Therefore, the primary objective of the current study was to evaluate the plateau slope of the tested wires at different conditions. Although all wires revealed an increase in the plateau slope following clinical use, yet Dentaurum wires had the lowest plateau slope value (Table 1 and Table 2). Hence, Dentaurum wires may provide a more favorable clinical performance.

The resilience/activation forces represent the energy stored in the NiTi wire as it is engaged into the bracket slot. Since orthodontic biomechanics is based on the conversion of stored elastic energy into mechanical energy during the tooth movement (15), comparison of the resilience values of the different brands of wires seemed necessary. The results revealed that the resilience of the wires was significantly affected by the intervention. During leveling and aligning, low stiffness wires are preferred since they deliver lighter and more constant forces during arch deactivation (16). Such stiffness is determined by the modulus of elasticity of the wire. Regarding the elastic modulus, in all subgroups, there was no statistically significant difference between wire brands. The lack of difference between the wires could be attributed to the fact that they all had the same cross-section and diameter. These findings agree with those reported by Garrec *et al.,* (2004) (17) who concluded that the wire size rather than the brand was a significant variable for stiffness. Oltjen *et al.,* (1997) (18) stated that wire stiffness was significantly affected by the size and number of strands as well as the alloy composition. The reduction in the modulus of each wire brand following intraoral use (Table 2) may be attributed to phase transformation that may have taken place due to intraoral aging and/or mechanical loading during mastication. However, further investigation is required to validate such finding.

Absence of any permanent deformation in the tested wires following their use (Figure 5) may be attributed to the superelastic property of the NiTi wires that allows delivering a constant force over a larger range of deactivation without permanently deforming (19). However, our results demonstrated that both immersion in saliva and introral use impacted the mechanical properties of the wires where the *in-vivo* groups revealed the highest plateau slope. On the other hand, the *in-vitro* resilience was higher than that obtained in the *in-vivo* group. Holec *et al.,* (2008) (20) stated that microcracks or microvoids that appear on the surface of the wire, may affect the mechanical properties of the wire and moreover, corrosion. This may explain the difference in between the as-received wires and those immersed in saliva for 8 weeks. Such effects were aggravated by the intraoral conditions in case of the *in-vivo* group.

The clinical performance of the wires and their crowding-relief ability was calculated using Little's Irregularity Index (LII) which measures the horizontal linear distance between anatomic contacts of the incisors in the labiolingual direction parallel to the occlusal plane, ignoring vertical displacement (21). The higher the index value, the more severe the labiolingual displacement of the teeth. Although, the LII was developed for use on the mandibular incisors to monitor relapse, researchers have used it to evaluate incisor irregularity in both arches (22-25). In the current study, 3shape Trios intraoral scanner was used to scan complete upper arches since it possesses one of the highest accuracies and precision between commercially available intraoral scanners at this time.

In the current study, despite the significant difference between the pre- and post-clinical inter-molar width resulting in case of the IMD wires (Table 3), no clinically significant difference in the relief of crowding was achieved by the different wire brands. Absence of any significant difference between the mean age values, gender distributions and between occlusion classes in all three groups may be thought to support our reported results. The differences in the amount of crowding relief obtained in the current study compared to other studies may be attributed to the difference in the duration of intraoral use and/or the use of wires with different diameters. Furthermore, evaluating the maxillary arch rather than the mandibular arch may have caused an increase in wire flexibility, resilience, and possibly the amount of tooth movement owing to the increase in the inter-bracket distance.

The results of the present study revealed that the wire brand did not affect the resolution of crowding. The chemical composition of the different brands of NiTi wires seems to be similar resulting in similar aligning efficiency, given that all wires had identical testing period. These findings are in agreement with those reported by both Riley and Bearn (2009) (26) and Jain *et al.,* (2021) (27) where no significant difference in the alignment efficiency between the tested archwires was evident. On the contrary, Nakano *et al.,* (1999) (13) reported great variation in force values delivered with different NiTi wires of the same diameter, indicating that despite the similar chemical composition of the wires, they are intrinsically different. This was attributed to the fact that the mechanical properties of NiTi alloy wires are greatly influenced by the different technological manufacturing parameters. Although the null hypothesis was rejected, since the results showed difference in mechanical properties between different brands of NiTi wires, yet the difference in the mechanical properties did not impact the clinical performance of the wires since our clinical findings revealed insignificant difference in the leveling and alignment achieved as measured using Little's Irregularity index. Further prospective randomized clinical trials should be carried out to reveal the long-term effects on the different types of NiTi archwires.

Conclusions

Despite the change in mechanical properties that took place in the three tested wire brands following intraoral use, their clinical performance was not impaired. There was no difference in the alignment efficiency between the different wire brands. All wires had similar clinical effects in terms of the changes in inter-canine and inter-molar width. Further studies are needed on severe crowding cases to confirm such findings.

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