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Original Article

Dentistry Section

A Comparative Analysis of Force Deflection Property of Nickel-Titanium Wires of Four Manufacturers using Five Point Bending Test: An In-vitro Study

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ABSTRACT

Introduction: Over the last century, material science has made rapid progress. In orthodontics, not only the materials improved, but also the philosophies have changed. Orthodontic wires, which generate biomechanical forces through brackets for tooth movement, are central to the practice of this profession.

Aim: To measure the force deflection properties of Nickel-Titanium (NiTi) wires of four manufacturers, used during orthodontic treatment.

Materials and Methods: In this in-vitro study, 480 NiTi wires from four different manufacturers [American Orthodontics (AO), 3M-Unitek (3M), Rabbit Force Orthodontics (RO) and Modern Orthodontics (MO)], of various cross-sections was obtained. Samples of each wire were obtained by cutting the straightest distal portion of an arch wire, thus an approximate length of 5.5 cms was recovered. These wires were subjected to a five point bending test. Five lower anterior stainless steel brackets of tooth number 31, 32, 41, 42 (MBT 0.022” Libral traders Centrino brackets) were fixed with the face of the bracket facing upwards on the acrylic block. Each NiTi wire was placed in the slots of orthodontic brackets and secured with stainless steel ligature wires. These wires were subjected to artificial saliva (Wet Mouth) for 30 days at 37°C. This temperature was regulated by using an incubator. The main assessment criterion was the force deflection property of the wire material. Force deflection was measured using a graph paper where initially the wire was placed and plotted on the graph paper. After the deflection of the wire, it was again placed on the same graph paper such that wire ends coincided and the force deflection at the highest point was measured in millimetres using a digital Vernier Caliper (Mitutoyu). The Design of Experiments (DOE) model was used for analysis and a three-way Analysis of Variance (ANOVA) with wire shape as covariate was used for analysing the variability.

Results: A 0.014” NiTi wire showed more mean deflection when compared to 0.016” NiTi wire. When a comparison between 0.016”×0.022” and 0.017”×0.025” NiTi wires was done, mean deflection was almost the same. When round and rectangular wires were compared it showed more mean deflection in round wires. When AO was compared with other three manufacturers. A significant difference (p-value <0.0001) was seen in the mean deflection values of MO and RO. When 3M was compared with the other three manufacturers a significant difference (p-value <0.0001) was seen in the mean deflection values of MO and RO. Three-way ANOVA test with wire shape as co-variate showed a significant amount of difference (p<0.0001) for AO, 3M wires with their counterparts.

Conclusion: Round NiTi wires showed more force deflection as compared to rectangular NiTi wires. AO and 3M wires were superior as compared to RO and MO wires. Superelastic wires showed more deflection as compared to conventional and heat-activated NiTi. This can be attributed to the property of the wire. Stiffer the wire, less deflection was seen. Cost of the wire also played a role. Cheaper wires were not able to match the quality and standards of their counterparts.

Keywords: Conventional, Elasticity, Heat-activated, Round, Rectangular, Superelastic

INTRODUCTION

Over the last century, there is a rapid progress in material science, also philosophies have changed in orthodontics. Orthodontic wires, which generate biomechanical forces through brackets for tooth movement, are central to the practice of this profession. While selecting the wire for orthodontic treatment, an orthodontist must keep various factors in mind such as amount of force delivery, elastic range or spring back, formability and the type of movement [1]. The properties of an ideal arch wire are stiffness, strength, range, spring back, formability, resiliency, coefficient of friction, and biocompatibility. During the early aligning and levelling stages of orthodontic treatment, more physiologically acceptable tooth movement can be achieved if light, continuous forces are used rather than heavier, intermittent forces. Low-stiffness wires are used to deliver these light forces, typically single-stranded Nickel-Titanium (NiTi) wires [2].

To accomplish this, an appliance should deliver optimum forces, which are light and continuous and should decay over a sufficiently long period of time. There are three types of NiTi wires : Conventional NiTi, Heat activated NiTi and superelastic NiTi. The properties of NiTi are shape memory, superelasticity, corrosion resistance, bio compatibility, resistance to torsional fracture [1]. The force required to align the teeth is not the activation force but the deactivation force (unloading force) of the appliance [3]. This deactivation force of various wires used in the initial stages may not be the same. Therefore, force-deflection graph generated during activation and deactivation of these wires might vary. Hence, thorough knowledge of these wires in terms of deactivation behaviour is important for the clinician for optimal wire selection. An ideal arch wire should be able to move teeth with a light, continuous force [4]. The force applied to the teeth should be designed in a way to minimise the patient discomfort, tissue hyalinisation, and root resorption. The arch wire, while applying the force should behave elastically over a period of months [5].

The arch wire of a fixed appliance is the major component in the alignment and levelling of irregular teeth. NiTi wires capable of large elastic deflections are popular as they allow greater working ranges and therefore fewer arch wire changes [6]. A comprehensive understanding of mechanical characteristics of orthodontic wires is essential so that the orthodontist can select the arch wire more suited for the specific phase of treatment to attain the required treatment goal. It is also necessary to take into account the biomechanics used [3,4,7].

Advancement in technology has resulted in the introduction of newer arch wires like superelastic NiTi and thermo activated NiTi. However, availability of so many arch wires from various commercial companies has led to the confusion in the clinician's mind to select the ideal arch wire during initial aligning [8]. The recent advances in the metallurgical industry have given rise to a large number of manufacturers and wide range of products. These manufacturers have been constantly trying to bring in newer and better products. Their sole aim is to bring in NiTi wires that have lesser force deflection and better patient comfort. Hence, the purpose of this study was to measure the force deflection properties of NiTi wires of four manufacturers used during initial stage of orthodontic treatment. For this study the null Hypothesis (H_0): The mean force deflection is similar for the four manufacturers, four wire gauges and three wire materials.

MATERIALS AND METHODS

This was an in-vitro study conducted at Department of Orthodontics, Bharati Vidyapeeth Dental College and Hospital, Navi Mumbai. The total duration of this study was four months (January 2016 to April 2016). The research protocol was initially submitted to the Institutional Ethical Committee and Review Board and after ethical approval (Clearance no: BVU/DCH/NM/1584) the study was designed accordingly.

Four hundred and eighty Ni-ti wires from four different manufactures of various cross-sections were obtained. A length of 5.5 cms for each wire was obtained by cutting the straightest distal portion of an arch wire [9]. These wires were subjected to a five point bending test. Five lower anterior (MBT 0.022" Libral traders Centrino brackets) stainless steel brackets were fixed with the face of the bracket facing upwards on the acrylic block with a water proof adhesive. Total 720 brackets were used for this study. Lower anterior brackets of tooth number 31,32,41,42 were used as they have identical prescription values. A total of 36 wires were tested on a single acrylic sheet. Totally four such sheets were used. The wires were tested in four batches- 1st to 3rd batch 144 wires were tested in each batch. In the 4th batch 48 wires were tested. The same acrylic sheets were re-used. Each NiTi wire was placed in the slots of orthodontic brackets and secured with stainless steel ligature wires. These wires were subjected to artificial saliva (wet mouth) for 30 days at 37°C in an incubator [9].

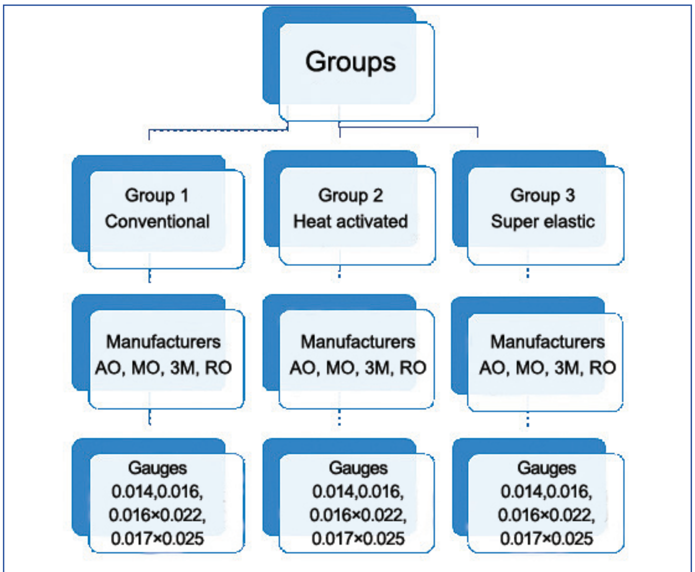
Sample size calculation: Sample size was not based on any assumptions and statistical estimations, and it was planned to have 10 samples from each of the smallest subgroup based on International Organization for Standardization (ISO) 15841 recommendation [10]. Thus, with 48 subgroups (four manufacturer's, four wire gauges and three materials) a total of 480 samples of wires were used for the study analysis methods [Table/Fig-1,2].

The commercially obtained sample was divided into three groups [Table/Fig-1]:

1. Group 1: Conventional NiTi Wires (160 wires)
2. Group 2: Heat-activated NiTi (160 wires)
3. Group 3: Superelastic NiTi. (160 wires)

These were further divided into subgroups based on their wire gauge [Table/Fig-2] .

1. Subgroup 1: 0.014" (round)- 10 wires
2. Subgroup 2: 0.016" (round)- 10 wires
3. Subgroup 3: 0.016"×0.022" (rectangular)- 10 wires
4. Subgroup 4: 0.017"×0.025" (rectangular)- 10 wires

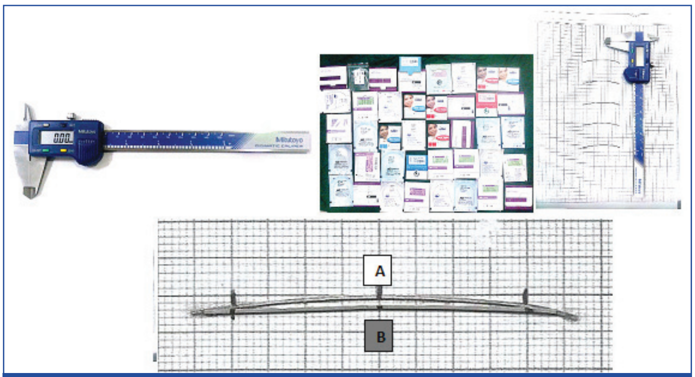


[Table/Fig-1]: Classification of sample size into groups and subgroups.

Group 1: Subgroups	Group 2: Subgroups	Group 3: Subgroups
1. AO 0.014	17. AO 0.014	33. AO 0.014
2. AO 0.016	18. AO 0.016	34. AO 0.016
3. AO 0.016×0.022	19. AO 0.016×0.022	35. AO 0.016×0.022
4. AO 0.017×0.025	20. AO 0.017×0.025	36. AO 0.017×0.025
5. MO 0.014	21. MO 0.014	37. MO 0.014
6. MO 0.016	22. MO 0.016	38. MO 0.016
7. MO 0.016×0.022	23. MO 0.016×0.022	39. MO 0.016×0.022
8. MO 0.017×0.025	24. MO 0.017×0.025	40. MO 0.017×0.025
9. 3M 0.014	25. 3M 0.014	41. 3M 0.014
10. 3M 0.016	26. 3M 0.016	42. 3M 0.016
11. 3M 0.016×0.022	27. 3M 0.016×0.022	43. 3M 0.016×0.022
12. 3M 0.017×0.025	28. 3M 0.017×0.025	44. 3M 0.017×0.025
13. RO 0.014	29. RO 0.014	45. RO 0.014
14. RO 0.016	30. RO 0.016	46. RO 0.016
15. RO 0.016×0.022	31. RO 0.016×0.022	47. RO 0.016×0.022
16. RO 0.017×0.025	32. RO 0.017×0.025	48. RO 0.017×0.025

[Table/Fig-2]: Classification of subgroups.
AO: American orthodontics; 3M: 3M-unitek; RO: Rabbit force orthodontics; MO: Modern orthodontics

The main assessment criterion was the force deflection property of the wire material. No load was being applied in this study as the aim was to measure the distortion of the wire post deflection. Force deflection was measured using a graph paper where initially the wire was placed and plotted on the graph paper [Table/Fig-3]. After the deflection (i.e., when the wire was retrieved after a period of 30 days from the bracket slot) it was again placed on the same graph paper such that wire ends coincided and the force deflection at the highest point (i.e., in between point A and B, Point A is the highest point on arch wire before it was tested and Point B is the highest point on the arch wire after it was tested) was measured in millimetres using a digital Vernier Caliper (Mitutoyu) [Table/Fig-3]. The measurements was carried out by the corresponding author and verified immediately by the other authors to minimise errors in taking readings. Totally two examiners verified the readings on the Vernier Caliper. The inter-examiner reliability score was 0.88. According



[Table/Fig-3]: Measurement of deflection of wire on graph paper, wires used and Vernier Caliper.

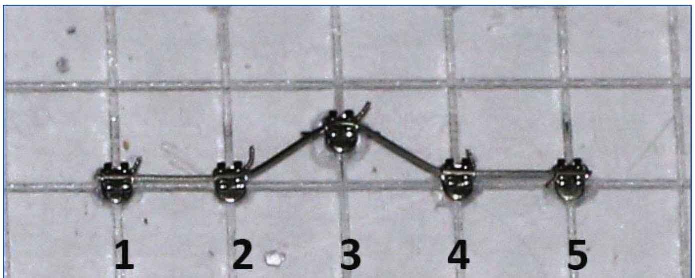
to Cohen's rating it shows almost perfect agreement [11]. Acrylic Sheets (Commercially obtained 16×30 cm clear acrylic sheet, 4 such sheets were used and the wires were tested in batches over a period of four months), 0.022" MBT Brackets (Centrino Brackets by Libral Traders Pvt. Ltd.), Vernier Caliper (Mitutoyu), Stainless Steel Ligature wire (Libral Traders Pvt. Ltd.), Armamentarium used were Pin and Ligature cutter, Artery forcep.

A total of 120 wires from each manufacturer were tested. Each group had 160 wires. Therefore, a total of 480 NiTi wires. The markings on acrylic sheets were made by computerised laser engraving [Table/Fig-4].

[Table/Fig-4]: Acrylic sheet with brackets placed (left); Acrylic sheet with markings by laser engraving (right).

Method of assessment: The study was conducted on acrylic sheets on which five standard stainless steel brackets were fixed using water proof adhesive [Table/Fig-4].

The 3-point bending test is recommended by ISO 15841 regulation [10]. Cue was taken from this to design the five point bending test. Five lower anterior (MBT 0.022") stainless steel brackets were fixed with the face of the bracket facing upwards on the acrylic block [Table/Fig-5]. Two brackets were placed on either side with a spacing of 1cm between them and the 3rd bracket was placed 5 mm upwardly on the mid-point perpendicular of the 2nd and 4th bracket. The ISO 15841 regulation: Dentistry-wires for use in orthodontics describe the distance between two supports to be 10 mm [10]. To standardise our test as adequately as possible the distance between two brackets was kept 1 cm/10 mm. Each NiTi wire was placed in the slots of orthodontic brackets and secured with stainless steel ligature wires. This distance determines the amount of displacement of wires. These wires were subjected to artificial saliva (Wet Mouth) for 30 days at 37°C in an incubator [Table/Fig-6].



[Table/Fig-5]: Stainless steel bracket positioning on acrylic sheet.

[Table/Fig-6]: Wires merged in artificial saliva (Wet Mouth) for 30 days at 37°C in an incubator.

STATISTICAL ANALYSIS

Software used for statistical analysis is Windows based statistical package Medcalc® version 12.7.5.0 (MedCalc Software bvba, Ostend, Belgium; http://www.medcalc.org; 2013).

Study Hypothesis

Null Hypothesis (H_0): The mean force deflection is similar for the four manufacturers, four wire gauges and three wire materials. Thus, the force deflection is not affected by the type of wire material, manufacturer and the gauge of material.

Alternate Hypothesis (H_1): The mean force deflection is not similar for atleast two manufacturers, wire gauges and wire materials. Thus, the force deflection is affected by the type of wire material, and/or the manufacturer of the material and/or the gauge of wires.

Data Expression

Data of force deflection (mm) is expressed as means with Standard Error of Mean (SEM). The Design of Experiments (DOE) model was used for analysis and a three-way Analysis of Variance (ANOVA) with wire shape as covariate was used for analysing the variability. The first factor is wire material, second factor is the wire gauge and the third factor is the manufacturer. All testing was done using two-sided tests with alpha 0.05. Thus, the criterion for rejecting the null hypothesis is p-value <0.05.

RESULTS

The null hypothesis of this study stands rejected. Thus, the force deflection is affected by the type of wire material, and/or the manufacturer of the material and/or the gauge of wires.

[Table/Fig-7] represents mean force deflection of 0.014" conventional NiTi arch wires of four manufactures. The mean deflection was highest for MO and least for AO.

Manufacturer	N	Mean	Std. Error	95% CI	p-value
AO	10	1.00	0.16	0.685 to 1.315	0.014*
3M	10	1.30	0.16	0.985 to 1.615	
MO	10	1.90	0.16	1.585 to 2.215	
RO	10	1.70	0.16	1.385 to 2.015	

[Table/Fig-7]: Mean deflection of conventional NiTi (0.014").
p<0.05*(Statistically significant); One-way Anova test used, CI: Confidence Interval

[Table/Fig-8] represents mean force deflection of 0.016" conventional NiTi arch wires of four manufactures. The mean deflection was highest for MO and least for AO.

Manufacturer	N	Mean	Std. Error	95% CI	p-value
AO	10	1.10	0.16	0.785 to 1.415	0.0578*
3M	10	1.20	0.16	0.885 to 1.515	
MO	10	1.70	0.16	1.385 to 2.015	
RO	10	1.40	0.16	1.085 to 1.715	

[Table/Fig-8]: Mean deflection of conventional NiTi (0.016").
p<0.05* (Statistically significant), One-way ANOVA test used

[Table/Fig-9] represents mean force deflection of 0.016"×0.022" conventional NiTi arch wires of four manufactures. The mean deflection was highest for MO and least for AO.

Manufacturer	N	Mean	Std. Error	95% CI	p-value
AO	10	1.00	0.16	0.685 to 1.315	0.014*
3M	10	1.30	0.16	0.985 to 1.615	
MO	10	1.90	0.16	1.585 to 2.215	
RO	10	1.70	0.16	1.385 to 2.015	

[Table/Fig-9]: Mean deflection of conventional NiTi (0.016"×0.022").
p<0.05* (Statistically significant); One-way ANOVA test used

[Table/Fig-10] represents mean force deflection of 0.017”×0.025” conventional NiTi arch wires of four manufactures. The mean deflection was highest for MO and least for Rabbit force orthodontics.

Manufacturer	N	Mean	Std. Error	95% C.I	p-value
AO	10	1.50	0.16	1.185 to 1.815	0.3463
3M	10	1.40	0.16	1.085 to 1.715	
MO	10	1.70	0.16	1.385 to 2.015	
RO	10	1.30	0.16	0.985 to 1.615	

[Table/Fig-10]: Mean deflection of conventional NiTi (0.017”×0.025”).
p<0.05* (Statistically significant); One-way ANOVA test used

[Table/Fig-11] represents mean force deflection of 0.014” Heat-Activated NiTi arch wires of four manufactures. The mean deflection was maximum for MO and least for AO.

Manufacturer	N	Mean	Std. Error	95% CI	p-value
AO	10	1.50	0.16	1.185 to 1.815	0.0001**
3M	10	1.70	0.16	1.385 to 2.015	
MO	10	2.60	0.16	2.285 to 2.915	
RO	10	2.30	0.16	1.985 to 2.615	

[Table/Fig-11]: Mean deflection of heat-activated NiTi (0.014”).
p<0.001** (Statistically highly significant); One-way ANOVA test used

[Table/Fig-12] represents mean force deflection of 0.016” Heat-Activated NiTi arch wires of four manufactures. The mean deflection was maximum for MO and least for AO.

Manufacturer	N	Mean	Std. Error	95% CI	p-value
AO	10	1.50	0.16	1.185 to 1.815	0.0001**
3M	10	1.70	0.16	1.385 to 2.015	
MO	10	2.60	0.16	2.285 to 2.915	
RO	10	2.30	0.16	1.985 to 2.615	

[Table/Fig-12]: Mean deflection of heat-activated NiTi (0.016”).
p<0.001** (Statistically highly significant); One-way ANOVA test used

[Table/Fig-13] represents mean force deflection of 0.016”×0.022” Heat-Activated NiTi arch wires of four manufactures. The mean deflection was maximum for MO and least for AO.

Manufacturer	N	Mean	Std. Error	95% CI	p-value
AO	10	1.20	0.16	0.885 to 1.515	0.0284*
3M	10	1.30	0.16	0.985 to 1.615	
MO	10	1.80	0.16	1.485 to 2.115	
RO	10	1.70	0.16	1.385 to 2.015	

[Table/Fig-13]: Mean deflection of heat-activated NiTi (0.016”×0.022”).
p<0.05* (Statistically significant), One-way ANOVA test used

[Table/Fig-14] represents mean force deflection of 0.017”×0.025” Heat- Activated NiTi arch wires of four manufactures. The mean deflection was maximum for Rabbit force Orthodontics and least for 3M-Unitek.

Manufacturer	N	Mean	Std. Error	95% CI	p-value
AO	10	1.00	0.16	0.685 to 1.315	0.0002**
3M	10	0.90	0.16	0.585 to 1.215	
MO	10	1.50	0.16	1.185 to 1.815	
RO	10	1.90	0.16	1.585 to 2.215	

[Table/Fig-14]: Mean deflection of heat-activated NiTi (0.017”×0.025”).
p<0.001** (Statistically highly significant); One-way ANOVA test used

[Table/Fig-15] represents mean force deflection of 0.014” Superelastic NiTi arch wires of four manufactures. The mean force deflection was maximum for MO and least for AO.

[Table/Fig-16] represents mean force deflection of 0.016” Superelastic NiTi arch wires of four manufactures. The mean deflection is maximum for MO and least for AO.

Manufacturer	N	Mean	Std. Error	95% CI	p-value
AO	10	2.10	0.16	1.785 to 2.415	0.0284*
3M	10	2.20	0.16	1.885 to 2.515	
MO	10	2.70	0.16	2.385 to 3.015	
RO	10	2.60	0.16	2.285 to 2.915	

[Table/Fig-15]: Mean deflection of superelastic NiTi (0.014”).
p<0.05* (Statistically significant); One-way ANOVA test used

Manufacturer	N	Mean	Std. Error	95% CI	p-value
AO	10	0.90	0.16	0.585 to 1.215	0.0001**
3M	10	1.30	0.16	0.985 to 1.615	
MO	10	2.30	0.16	1.985 to 2.615	
RO	10	1.50	0.16	1.185 to 1.815	

[Table/Fig-16]: Mean deflection of superelastic NiTi (0.016”).
p<0.001** (Statistically highly significant); One-way ANOVA test used

[Table/Fig-17] represents mean force deflection of 0.016”×0.022” Superelastic NiTi arch wires of four manufactures. The mean force deflection was maximum for MO and least for AO, 3M Unitek.

Manufacturer	N	Mean	Std. Error	95% CI	p-value
AO	10	1.50	0.16	1.185 to 1.815	0.4611*
3M	10	1.50	0.16	1.185 to 1.815	
MO	10	1.80	0.16	1.485 to 2.115	
RO	10	1.70	0.16	1.385 to 2.015	

[Table/Fig-17]: Mean deflection of superelastic NiTi (0.016”×0.022”).
p<0.05* (Statistically significant), One-way ANOVA test used

[Table/Fig-18] represents mean force deflection of 0.017”×0.025” Superelastic NiTi arch wires of four manufactures. The mean force deflection was maximum for Rabbit force Orthodontics and least for AO.

Manufacturer	N	Mean	Std. Error	95% CI	p-value
AO	10	1.20	0.16	0.885 to 1.515	0.0187*
3M	10	1.40	0.16	1.085 to 1.715	
MO	10	1.70	0.16	1.385 to 2.015	
RO	10	1.90	0.16	1.585 to 2.215	

[Table/Fig-18]: Mean deflection of superelastic NiTi (0.017”×0.025”).
p<0.05* (Statistically significant); One-way ANOVA test used

The comparison of the mean force deflection of four manufacturers (conventional NiTi): AO, 3M, MO, RO (Libral) of four gauges (0.014”, 0.016”, 0.016”×0.022”, 0.017”×0.025”). The mean force deflection was least for AO and 3M-Unitek. It was maximum for Rabbit Force Orthodontics and MO.

The comparison of the mean force deflection of four manufacturers (Heat activated NiTi): AO, 3M, MO, RO (Libral) of four gauges (0.014”, 0.016”, 0.016”×0.022”, 0.017”×0.025”). The mean force deflection was least for AO and 3M-Unitek. It was maximum for MO and RO. The comparison of the mean force deflection of four manufacturers (Superelastic NiTi): AO, 3M, MO, RO (Libral) of four gauges (0.014”, 0.016”, 0.016”×0.022”, 0.017”×0.025”). The mean force deflection was least for AO and 3M-Unitek. It was maximum for MO and RO.

[Table/Fig-19,20] shows that when AO was compared with other three manfacturers 3M, MO, RO (Libral Traders Pvt. Ltd.). A significant difference (p-value <0.0001) was seen in the values of MO and Rabbit Force Orthodontics.

Manufacturer	Manufacturer	Mean difference	Std. Error	p-value	95% CI
AO	3M	-0.1	0.065	0.761	-0.27 to 0.007
	MO	-0.66	0.065	<0.0001*	-0.83 to -0.49
	RO	-0.54	0.065	<0.0001*	-0.71 to -0.37

3M	AO	0.1	0.065	0.761	-0.07 to 0.27
	MO	-0.56	0.065	<0.0001*	-0.73 to -0.39
	RO	-0.44	0.065	<0.0001*	-0.61 to -0.27
MO	AO	0.66	0.065	<0.0001*	0.49 to 0.83
	3M	0.56	0.065	<0.0001*	0.39 to 0.73
	RO	0.12	0.065	0.45	-0.06 to 0.29
RO	AO	O.54	0.065	<0.0001*	0.37 to 0.71
	3M	0.44	0.065	<0.0001*	0.27 to 0.61
	MO	-0.12	0.065	0.45	-0.29 to 0.06

[Table/Fig-19]: One-way ANOVA test for comparison between various manufacturers.
Based on observed means; The error term is Mean Square (Error)=0.256; *The mean difference is significant at the 0.05 level

the β (beta) lattice with the addition of Molybdenum Columbium, a titanium alloy can maintain its β structure even when cooled to room temperature [1]. The manufacturing process can also influence the quality of the wire if all the process is not followed.

Superelasticity is a phenomenon in which the stress value remains fairly constant upto a certain point of wire deformation, at the same time when the wire deformation rebounds the stress value again remains fairly constant [4,7]. An ideal arch wire should retain a stable pre designed arch form at mouth temperature and yet be formable at a lower room temperature in other words it should be possible to engage the wire into the brackets during a reasonable time interval and only later the wire should recover its ideal arch form and apply light predictable constant and continuous force to the dento-alveolar structures [14]. Superelastic NiTi wires meet these requirements [4].

Source	Type III sum of squares	Degree of freedom (DF)	Mean square	F-value	p-value	Partial Eta squared	Non centrality parameter	Observed power
Corrected model	95.567[a]	47	2.033	7.928	<0.0001	0.463	372.606	1
Intercept	210.003	1	210.003	818.786	<0.0001	0.655	818.786	1
Shape	0	0	-	-	-	0	0	-
Manufacturer	37.717	3	12.572	49.018	<0.0001	0.254	147.054	1
Material	6.154	2	3.077	11.997	<0.0001	0.053	23.995	0.995
Gauge	14.433	2	7.217	28.137	<0.0001	0.115	56.274	1
Manufacturer material	2.446	6	0.408	1.589	0.149	0.022	9.536	0.612
Manufacturer gauge	4.883	9	0.543	2.116	0.027	0.042	19.040	0.878
Material * Gauge	10.129	6	1.688	6.582	<0.0001	0.084	39.493	0.999
Manufacturer * Material * Gauge	9.004	18	0.500	1.950	0.011	0.075	35.106	0.976
Error	110.800	432	0.256					
Total	1500.000	480						
Corrected total	206.367	479						

[Table/Fig-20]: ANOVA (Three-Way with wire shape as Covariate) of manufacturer, material and gauge.
Tests of variance between-Subjects Effects; Dependent Variable: Deflection; [a]R Squared=0.463 (Adjusted R Squared=0.405); [b]Computed using alpha=0.05, p-value <0.05 considered significant

DISCUSSION

In orthodontic treatment, the aims and objectives according to the Jackson's Triad are to establish functional efficiency, structural balance and aesthetic harmony. A well aligned arch plays an integral part in dental aesthetics. When wires that align the dental arches are inserted into the bracket slot an active force is exerted on the tooth [12,13]. Therefore, it becomes very important for the clinician to use an ideal arch wire that exerts an optimum force and that can perform this function very effectively and efficiently.

With the emergence of advances in metallurgical industry and technology the market has been flooded with large number of NiTi wires manufactured by several companies [8]. Today there are a vast number of manufacturers like Ormco, Ortho Organizers, Forestadent, 3M Unitek, JJ Orthodontics, AO, MO, Panama Orthodontics, Ortho Systems, RO, Captian Orthodontics, Galaxy Orthodontics, G&H Orthodontics, Jaipur Orthodontics, TP Orthodontics, Fox Orthodontics, Rocky Mountain, Sankin, A-Company, Gac International, Masel Orthodontics etc. Thus, a wide range of wires that are available has led to a question in the clinician's mind as to which wire would be the ideal arch wire and which one should be used. Another factor that an orthodontist might give consideration to is the cost. The properties of an ideal arch wire are stiffness, strength, range, spring back, formability, resiliency, coefficient of friction, and biocompatibility [4].

The method of manufacturing NiTi is titanium is obtained in its pure form by heating the titanium ore in presence of carbon and chlorine. The Titanium-tetra-chloride (TiCl4) is then reduced with sodium to produce a titanium sponge. This sponge is fused under vacuum or in inert argon atmosphere and converted to ingots. Pure Titanium exhibits allotropy undergoing crystallographic change at 885°C. At temperatures below 885°C, the Hexagonal Close Packed (HCP) lattice or the α (alpha) lattice is stable. While at higher temperatures, the metal rearranges into the Body Centered Cubic (BCC) lattice or

Superelasticity of NiTi wires is manifested by very large reversible strains and a non-elastic stress strain curve or force deflection curve. The unique force deflection curve for NiTi wires occurs because of a phase transition in grain structure from austenite to martensite, in response not to a temperature change but to applied force. The transformation is a mechanical analogue to thermally induced shape memory effect [4]. Heat-Activated NiTi gets activated at various temperatures so it is commonly used in severely crowded cases. Due to this property it is easy to insert clinically [1].

The wire and bracket slot relationship also plays an important role in the force deflection of these wires. In pre-adjusted edgewise system when the wire is engaged into the slot of the brackets due to the slot angulation the tip and torque are expressed. Therefore, a precise wire also requires a precise bracket slot. Therefore, while selecting an ideal arch wire it is also important to select an ideal bracket [15-17].

The deflection and the load in the bending of wires using a three point bending test was studied by Hirokazu N et al., [18]. The universal testing machine (Autograph DSS-5000, Shimazu Co., Tokyo) was used to measure the values. Margherita S et al., also studied the properties using three point bending test [19]. But the study design was different. The test done by Luca L et al., had four brackets on acrylic resin base. This study was stimulating a clinical condition where point 3 indicated a highly placed canine [9]. In three point test a load is applied for deflection of wire. In this study distortion of wire is because of point/bracket number 3 as the aim of this study is to measure distortion of wire post deflection. The 5 point bend test is different from the 3 point test as point 1 and 5 were added to give more stability to wire while deflection when engaged into the bracket slots. The loading device in similar studies was built of plexiglass to take advantage of the electrical insulation properties of the material [15]. A rectangular platform supported a step (tooth) of rectangular section.

Vestibular surfaces of the 2 most displaced lower incisors were 1 mm; 1 of the 2 central teeth was, therefore, 1 mm high [15, 20]. Two columns of brackets were glued to the base of the loading device, close to the central tooth. Another column of brackets was glued on the surface of the central tooth. As a result, 10 rows of 3 brackets each, with the crowded tooth (either 1 or 6 mm in height) supporting the central bracket, were available to load the specimens. The wires were engaged to the brackets with elastomeric ligatures. Nikolaos P and Christoph PB, and Robert PK and John QW studied the properties using three point bending test but with a slight variation in study design [21,22]. Biomechanical testing of the wire was done in simulated clinical situation. In Robert PK and John QW study, there was a loading platform with centrally located reference pan and specimen pan [22]. A temperature controlled chamber in vertical plane (heating and cooling). This study design had an enclosed chamber so that the temperature could be regulated.

In this study, MO showed maximum mean deflection in Heat-Activated NiTi in wires of all dimensions. Rabbit Force Orthodontics showed maximum mean deflection across all dimensions of wires in conventional NiTi. This study is important from a clinical perspective as it aims to give a direction to the clinicians so that an ideal wire can be selected. The clinicians should know the properties of various types of NiTi so that the wire most suited for the intended movement is selected. The main property of NiTi wires is spring back action and shape memory. Hence it is used in the initial stages of Orthodontic treatment to align severely malaligned teeth. This function cannot be performed by stiff Stainless Steel wires. Therefore, NiTi wires are the wires of choice during initial stages of Orthodontic treatment. NiTi wires are composed of Nickel (50%) and Titanium (50%) hence the name NiTi [1]. In order to bring the transitional temperature to 37°C now-a-day's cobalt (1.6%) is added to the alloy. They are also used as transitional wires from NiTi to stainless steel.

Superelastic alloys also exhibit hysteresis, that is the activation and deactivation plateaus have different stress magnitudes. As a result, the wire does not deliver the same force as that applied to activate it. Hysteresis can also be thought of as the friction associated with the movement of twin related martensite boundaries. The magnitude of hysteresis depends on the alloy composition [23]. During the manufacturing process if parameters may not have been adjusted optimally, it would result in less than ideal product properties. Minute differences in the manufacturing process, have a significant impact on the behaviour of the product [23,24]. Among these are nickel content, oxygen content, processing heat treatment, and work hardening history [13]. Superelastic NiTi showed maximum deflection when compared to Conventional and Heat-activated NiTi in the present study. Thermal copper NiTi has the lowest load/deflection ratio and can be used to correct severe crowding efficiently and effectively, by easily engaging to the brackets with least effort [25-27]. The results of this study agree with the study of Lombardo L et al., who observed mechanical properties of NiTi alloy wires are greatly influenced by parameters such as chemical composition, heat treatment. Minor difference in production process of super elastic wires can lead to sizeable thermo mechanical variations in the behaviour of the arch wires [5,28,29]. Pratten DH et al., disagree with result of this study they stated that types of ligature and design of brackets had significantly influenced on the actual amount of deactivation force than wire manufacturer that both affect the frictional force [30].

The method of retrival of wire also could have influenced the results as seen in other studies [31]. The force expressed when wire is placed in bracket slot depends on type of wire and size. But the present study revealed that force depends even on the brand of wire being used. Temperature also has an effect on the mechanical behaviour of NiTi wires. This study agrees with it [32,33]. In a comparative study by Sathler R et al., elastic deflection results showed differences between three point test and Clinical Simulation Device (CSD) [34]. The present study is similar to 3-point test hence it is more reliable because of precision, clinical similarity and reproducibility.

Limitation(s)

There were certain limitations in this study such as only NiTi wires from four manufacturers were examined. Many other types of wires used in Orthodontics were not examined. The wires examined were by manufacturers commonly used by orthodontists; this was based on the authors assumption. Only a single parameter of force deflection of NiTi was measured. The method of bending test used could also influence the results. Further research is required in this field. Studies like this one, throw more light on the correctness of the claims made by various manufactures while marketing their products. This provides the base and scope for further research where wires made by more manufacturers can be studied.

CONCLUSION(S)

In clinical practice, it is most important to select the ideal arch wire that can perform its function effectively and efficiently. The null hypothesis of this study has been rejected. The mean force deflection is not similar for at least two manufacturers, wire gauges and wire materials. Thus, the force deflection is affected by the type of wire material, and/or the manufacturer of the material and/or the gauge of the wires. Based on the recorded data and statistical analysis and after a comparative analysis of force deflection property of NiTi Wires using a five point bending test, from this study the following conclusions can be drawn: AO and 3M were superior as compared to RO and MO, as AO and 3M showed least amount of force deflection. Superelastic wires showed more deflection as compared to Conventional and Heat-activated NiTi. Stiffer the wire, lesser was the deflection seen. i.e.,: 0.017”×0.025” NiTi wire showed lesser deflection compared to 0.016”×0.022” NiTi wire for the wires by four manufacturers used in this study. For all the wires made by different manufacturers the common finding was that round NiTi wires showed more force deflection as compared to rectangular NiTi wires. The variation in the manufacturing process of various manufacturers and the raw material used and temperature could have influenced these results.

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