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Evaluation of Mechanical Properties of Niti and CuNiti Archwires in as Received and After Artificial Aging

Mostafa Kareem Sofar, Reem Atta Rafeeq*

Department of Orthodontics, College of Dentistry, University of Baghdad, Baghdad, Iraq

ABSTRACT

Introduction: The archwires for initial alignment stage require a combination of excellent strength, excellent springiness and a long range of action. Metal appliances including orthodontic archwires are prone to corrosion or degradation in the oral environment due to different salivary components, pH levels and thermal fluctuations that may affect their performance.

Aim: The purpose of the current in vitro study is to assess the impact of static deflection, thermo-cycling and acidic exposure on load deflection behaviors of nickel titanium and copper nickel titanium archwires.

Materials and Methods: Samples of Niti and CuNiti, 0.016 inch, were divided into four groups: 1, as-received; 2, water storage (2 months); 3, thermo-cycling (5000 cycles); 4, acid challenge (pH 2.5). Loading and unloading forces at 0.5mm intervals were measured using modified bending test. One-way ANOVA and independent t-test were applied to compare the means and Tukey's post hoc test used when there was significant difference.

Results: At each deflection, Niti archwires have the highest load values compared to CuNiti archwires in both loading and unloading phases. There is a significant difference between Niti and CuNiti archwires regarding plateau gap and hysteresis percentage. No significant difference have been recorded among different conditions for Niti archwire, while there was significant difference for CuNiti archwire.

Conclusion: CuNiti archwires have light and more constant force compared to Niti archwires. However Niti archwires are more resistant to in vitro aging compared to CuNiti archwires. Thermo-cycling reduce the hysteresis between loading and unloading phase while acid challenge increase it for CuNiti archwires.

Key words: Niti, CuNiti, Thermo-cycling, Acid challenge

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Corresponding author: Reem Atta Rafeeq

e-mail✉: Mksofar@uowasit.edu.iq

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INTRODUCTION

Leveling and aligning constitute the initial phase of the comprehensive fixed orthodontic treatment. The archwires used during this phase should have good working range that provide light and constant forces for efficient tooth movement [1].

Andreasen and Hilleman were release Nickel-titanium (Niti) orthodontic archwires firstly to the orthodontics in 1971 [2]. Mechanical properties, such as low stiffness, high springback, shape memory and superelastic properties are common features of these alloy [3]. Generally there archwires can be categorized based on their structure into: (1) martensitic stabilized, which exhibit no shape memory or superelasticity; (2) martensitic active, in which a temperature raise will result in transformation of the martensitic into the austenitic structure; and (3) austenitic active, in which the martensitic structure transformation is stress-induced [4].

Copper-nickel-titanium (CuNiti) archwires have developed from a continuous efforts to improve orthodontic technologies, and its chemical composition corresponds to approximately 50.7% Ni, 42.4% Ti, and 6.9% Cu [5]. These archwires have greater elasticity which permit for the constant force transmission over a long time period thus increasing the time concerning archwire replacement procedures [6].

Orthodontic appliances usually stay in the challenging environment of oral cavity for a long term duration where they are exposed to chemical, thermal and mechanical factors, and this could influence the orthodontic archwires physical and mechanical qualities [7,8]. To the best of authors knowledge, there are little facts concerning the effect of in vitro aging on the mechanical properties of Niti and CuNiti archwires and the majority of published load-deflection properties results are restricted to the as-received condition [9,10], even though clinicians use the archwires under various stresses and strains in the corrosive oral conditions for a couple of months; therefore, the aim of the present study is to assess the load-deflection properties of Niti and CuNiti archwires in as-received and after in vitro aging process using modified bending test.

MATERIALS AND METHODS

Materials

The archwires used in this study were preformed 0.016-in conventional superelastic nickel titanium (Dentarum GmbH & Co.KG, Ispringen, Germany) and superelastic copper nickel titanium (Ormco, Glendora, USA). For each archwire type, 30 mm long pieces were cut from the nearly straight posterior sections. Consequently a total of 48 archwire segments, 24 of each type were obtained. Six segments of each archwire type were tested in as received, while the remaining segments were underwent in vitro aging and divided into 3 subgroups as the following: static stress, thermo-cycling and acid challenge subgroups.

In vitro aging

In order to simulate intraoral environment, the archwire segments underwent an artificial aging. They kept under static load deflection at 3 mm using 0.022 x 0.028-in MBT brackets (discovery ® smart, Dentarum GmbH & Co.KG, Ispringen, Germany) glued with cyanoacrylate adhesive to plastic block designed and made using CO2 laser computerized numerical control cutting machine. Ligature elastics (IOS, St. Stafford, TX, USA). were used to hold the archwire segments inside the brackets slot. The interbrackets centers distances were set to be 7.5 mm and this was based on the standard tooth dimensions (accurate to within 0.5 mm) for a male's maxillary permanent dentition in order to simulate a clinical situation where the maxillary canine is highly buccally malposed (Figure 1) [11].

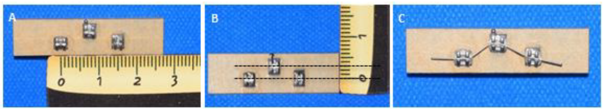

Figure 1: A and B, brackets bonded to blocks; C, blocks with wire segments deflected inside the brackets.

The deflected wire segments were subjected to three distinct artificial ageing models as the following:

✓ Water storage (WS): Six deflected wire segments from each archwire types were stored in deionized distal water (DW) and incubated at 37˚C for two months.

✓ Thermo-cycling treatment (TH): Six deflected wire segments from each archwire types were subjected to thermo-cycling regime of 5000 cycles between hot (55°C) and cold (5°C) water baths with 30 seconds dwell time in each bath and 5 seconds transfer time [12]. Once completed, the samples were kept in DW inside the incubator at 37˚C for the remained period of the study duration (2 months).

✓ Two months Acid Challenge (AC): Six deflected wire segments from each archwire types were immersed in HCL acid (pH=2.5) following the protocol of three sessions per day, five minutes each, with two hours equal intervals. In order to mimic the wet oral environment, the samples were kept in DW at 37˚C for the rest of the day, after being washed and dried before and after each session. Samples were initially immersed in DW at 37°C for 24 hours ahead of performing the AC experiment. An acidic solution (pH=2.5) of 500ml was prepared by gradually adding 1.5ml of 1M HCl with DW, and pH value of acidic solution were measured using digital pH meter (Jenway 3510, Staffordshire, UK). The acidic solutions and DW were replenished after each session [13].

Bending test

After two months of in vitro aging, both as received and aged archwire segments were subjected to modified bending test to simulate clinical conditions as accurately as possible. To conduct the test, a custom U-shaped acrylic experimental model was prepared with two brackets (0.022x0.028-in upper lateral and 1st premolar brackets) glued to the model using cyanoacrylate adhesive in which their slots were aligned and leveled in all three planes of space (using a piece of 0.021×0.025-in wire). The distance between the midpoints of the lateral and 1st premolar brackets according to Wilkinson's standards was 15 mm (Figure 2) [10].

Based on ISO standard, the tests were conducted at a similar testing temperature of 37±1°C for all test groups, which represents the intraoral temperature for nasal breathers [10,13,14]. To obtain this, the acrylic model was placed in a digital water bath (HH-S, Zhejiang, China) filled with DW and kept at a constant temperature of 37 ± 1°C with the aid of submersible heater with thermostat. The wires were placed and maintained in the conventional brackets using elastomeric ligature. Each sample was kept in DW for at least 60 seconds ahead of being underwent the testing procedure to achieve thermal equilibrium (Figure 3).

Tinius Olsen testing machine (computerized instron H50KT, England) with 10N load cell was used to evaluate the wire deflection properties. The force was exerted vertically, on the midpoint of the wire between the lateral incisor and 1st premolar brackets at a crosshead speed of 2 mm/min for 3 mm deflection through a rod mounted on the moving head of the machine. Loading and unloading amounts of forces were

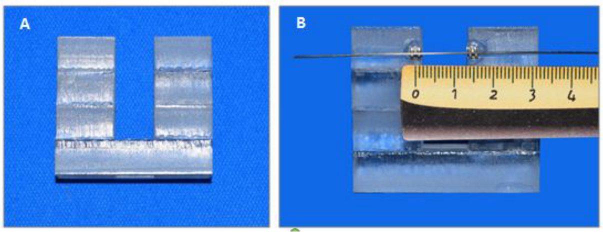

Figure 2: A, Custom made U-shape acrylic block; B, 0.022 slot brackets bonded to the block with aid of 0.021 x 0.025-in SS wire.

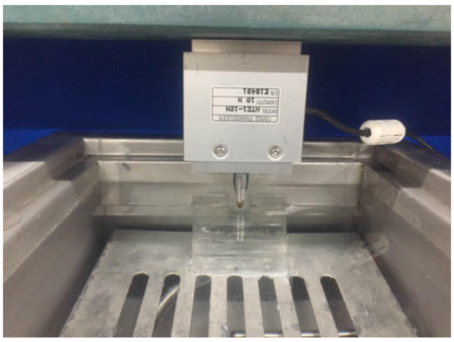

Figure 3: Modified load deflection bending test of archwire segment.

recorded. The data were obtained by a personal computer connected to the machine and were processed utilizing QMAT software. The following measurements were made:

Loading and unloading force values at 0.5 mm deflection intervals.

Percentage of hysteresis: which represents the loss of energy between the loading and unloading value at 1.5mm deflection, was calculated by the following equation:

Percentage of hysteresis=(LDP−UDP)/LDP X 100%.

LDP: Load deflection point, UDP: Unload deflection point.

3-Percentage of plateau gap (PG): representing the percentage of force decline in the plateau gap that will be calculated by dividing the plateau gap to the load at 2.5 mm deflection of unloading phase multiply by 100%.

Percentage of P.G=(UDP1-UDP2)/UDP1 X 100%

Statistical analysis

The statistical procedures were carried out using a computer software (SPSS, version 26, Chicago, USA). All data sets are expressed as the mean and standard deviation (SD). The Shapiro–Wilks and Levene's tests were used for examination of the normality of distribution and the equality of variances between groups. Since the data were normally distributed, therefore; they were analyzed through parametric tests including: one way ANOVA and unpaired T-test. Statistical significance was considered for a p-value <0.05.

RESULTS

Table 1 shows the mean and standard deviation (S.D) for the loading and unloading forces (in N) of 0.016-in Niti and CuNiti archwires. At each deflection, Niti archwires have the highest load values compared to CuNiti archwires in both loading and unloading phases. For both archwire types, the force values were increased with increasing the amount of deflection in all subgroups. The load values of Niti archwire during both loading and unloading phases were comparable among the subgroups at each deflection. While for CuNiti archwire, AC subgroup record the highest load values at loading phase and lowest values for unloading phase.

Figure 4 and Figure 5 show the load deflection curves of the Niti and CuNiti archwires in as-received and after artificial aging conditions respectively. During loading and unloading situations, the archwires exhibited typical super elastic properties in that horizontal plateau and hysteresis loops were markedly appeared.

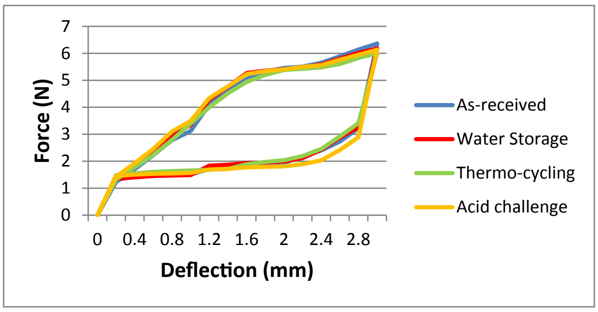

Figure 4: Load deflection curves for 0.016 inch Niti arch wires in as-received and artificial aging conditions.

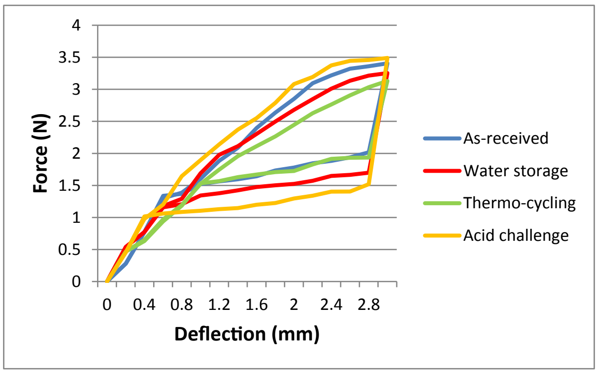

Figure 5: Load deflection curves for 0.016 inch CuNiti archwires in as-received and artificial aging conditions.

Table 2 shows comparison of plateau gap and hysteresis percentages between Niti and CuNiti archwires in as-received and after artificial aging conditions using unpaired t-test. The results indicated that there is significant difference ($P \leq 0.05$) in plateau gap percentage between Niti and CuNiti archwires at all conditions. Also for the hysteresis percentage, there is a significant difference ($P \leq 0.05$) between at as-received, WS and TH subgroups, while a non-significant difference at AC subgroup. Table 3 shows comparison among different conditions for each archwire types using one-way ANOVA test, and a highly significant difference ($P \leq 0.01$) was demonstrated in hysteresis percentage among the aging conditions for CuNiti archwire, while

Table 1: Descriptive statistics of force (in N) during loading and unloading of 0.016 inch Niti and CuNiti archwires in as received and after artificial aging.

Archwire	Condition	Loading Mean (SD)					Unloading Mean (SD)			
		1mm	1.5mm	2mm	2.5mm	3mm	2.5mm	2mm	1.5mm	1mm
Niti	AR	3.12 (0.59)	4.84 (0.28)	5.45 (0.15)	5.75 (0.15)	6.36 (0.15)	2.56 (0.51)	2.00 (0.41)	1.82 (0.5)	1.52 (0.16)
	WS	3.33 (0.67)	5.09 (0.07)	5.4 (0.14)	5.58 (0.26)	6.17 (0.23)	2.62 (0.38)	1.99 (0.38)	1.90 (0.39)	1.48 (0.29)
	TH	3.39 (0.42)	4.77 (0.33)	5.38 (0.16)	5.51 (0.19)	6.0 (0.15)	2.67 (0.56)	2.03 (0.43)	1.73 (0.81)	1.65 (0.11)
	AC	3.08 (0.72)	5.1 (0.06)	5.4 (0.03)	5.6 (0.11)	6.13 (0.03)	2.22 (0.12)	1.80 (0.2)	1.75 (0.17)	1.56 (0.01)
CuNiti	AR	1.61 (0.49)	2.64 (0.31)	2.65 (0.46)	3.27 (0.12)	3.40 (0.06)	1.92 (0.14)	1.77 (0.17)	1.61 (0.2)	1.52 (0.15)
	WS	1.88 (0.5)	2.21 (0.14)	2.68 (0.11)	3.06 (0.1)	3.25 (0.17)	1.74 (0.61)	1.52 (0.54)	1.44 (0.54)	1.34 (0.53)
	TH	1.56 (0.27)	1.79 (0.12)	2.44 (0.4)	2.82 (0.36)	3.13 (0.36)	1.93 (0.14)	1.72 (0.1)	1.63 (0.12)	1.53 (0.14)
	AC	1.89 (0.08)	2.83 (0.59)	2.82 (0.07)	3.28 (0.05)	3.48 (0.1)	1.40 (0.33)	1.29 (0.35)	1.15 (0.39)	1.10 (0.38)

AR: as received, WS: Water storage; TH: Thermo-cycling, AC: Acid challenge.

Table 2: Comparison of PG and hysteresis percentages between Niti and CuNiti archwires in as received and after artificial aging conditions using unpaired t-test.

Condition	PG%		t-test	p- value	Hysteresis %		t-test	p-value
	Niti	CuNiti			Niti	CuNiti		
AR	38.92 (11.83)	20.66 (7.67)	3.171	0.01	61.84 (12.33)	38.88 (4.66)	4.263	0.002
WS	42.53 (13.18)	24.98 (8.95)	2.697	0.022	62.46 (8.15)	35.65 (22.37)	2.758	0.02
TH	36.68 (8.92)	20.82 (7.33)	3.362	0.007	63.51 (5.28)	8.69 (4.32)	19.664	0
AC	29.53 (3.84)	15.93 (5.29)	5.092	0	65.51 (3.7)	60.1 (6.26)	1.823	0.098

Table 3: Comparing the PG and hysteresis percentages of Niti and CuNiti archwires among different aging conditions using ANOVA test.

Archwire	Condition	PG %	F-test	P- value	Hysteresis %	F-test	P-value
Niti	AR	38.92 (11.83)	1.766	0.186	61.84 (12.33)	0.24	0.868
	WS	42.53 (13.18)			62.46 (8.15)		
	TH	36.68 (8.92)			63.51 (5.28)		
	AC	29.35 (3.84)			65.51 (3.7)		
CuNiti	AR	20.66 (7.67)	1.484	0.249	38.88 (4.66)	18.39	0
	WS	24.98 (8.95)			35.65 (22.37)		
	TH	20.82 (7.33)			8.69 (4.32)		
	AC	15.93 (5.29)			60.1 (6.26)		

Table 4: Multiple comparisons between the groups using Post hoc Tukey HSD test.

Archwire	Condition		Mean difference	P-value
CuNiti	AR	WS	3.227	0.966
		TH	30.189	0.002
		AC	21.214	0.03
	WS	TH	26.962	0.005
		AC	24.441	0.011
	TH	AC	51.403	0

a non-significant difference for Niti archwires. However, there is a non-significant difference in plateau gap percentage among the aging conditions for both archwire types. Depending on a results from ANOVA, Tukey HSD test was performed to compare the hysteresis percentage between aging conditions for CuNiti archwires as seen in table 4. The Tukey HSD test show that there is a significant difference between TH subgroup and other subgroups. Also a significant difference between AC subgroup and AR and WS subgroups.

DISCUSSION

Bending method

The mechanical properties of archwire had been tested in majority of previous studies employing the cantilever or three-point bending tests which present a major drawbacks of poor results reproducibility, failure to reproduce the superelastic behavior of Niti archwires efficiently and did not replicate the situations experienced clinically [15]. Therefore, it has been suggested that the most appropriate archwire tests may be those whereby the archwire constrained as part of a fixed appliance [16]. Thus modified bending test was used in this and many other previous studies [3,10].

Artificial aging

The archwire segments of aging subgroups have been placed under static bending stress of 3mm, as an average for a clinically malaligned teeth [8]. The incubation temperature and duration were chosen to be 37˚C for 60 days, which signifies the regular oral cavity temperature and the time range that the archwires usually used clinically [17].

Thermo-cycling was performed as a way to simulate the oral cavity temperature variations when hot and cold beverages being consumed. It has been presented as an artificial aging method intended for assessing the effect of thermal stresses on dental materials [18].

An aggressive acid challenge protocol was adopted in the present study also to simulate a clinical scenario whereby an orthodontic patient consuming an extremely acidic beverage (pH 2.5) three times/day with five minutes consumption period for a duration of two months [13,19].

Load-deflection behavior

Low and constant force level produced by orthodontic archwire is necessary, however, archwires could be impacted by oral environment which could modify their mechanical properties [7,8,20]. On loading, the archwires have a tendency to return to its original shape and offers the force needed to move the teeth into alignment. Hence, it can be determined that deactivation load (unloading) is even more essential than loading [21].

Optimal orthodontic forces concept has been reviewed since the early 20th century. Ren et al. [22], in their meta-analysis concluded that there is no evidence regarding orthodontic optimal force levels. Rock and Wilson [23] assumed that the appropriate force magnitude to be used with fixed orthodontic appliances may be about 4N, while Proffit et al. [24] mentioned that the applied force must be over the biological threshold (0.5-0.7N) but should never exceed the biological corridor (2-3N), and the results of the present study revealed that the unloading forces for both archwires were within that range. CuNiti archwire exerted the lowest while Niti archwire exerted the highest force level at maximum deflection and unloading phase and these results are in agreement with many studies [8,10,25,26]. An explanation for this difference could be due to the higher austenite finish (Af) temperature of CuNiti archwire resulting from copper addition. Consequently, the critical stress required to induce martensite in low Af archwire is higher than that in high Af archwire [27].

The clinical significance of hysteresis is that the force delivered to the periodontal structures is low compared to the force applied for archwire activation [28]. In this study, both archwire types have a clear stress hysteresis in as received and in vitro aging (Figure 4 and Figure 5), but the Niti archwire have the highest percentage of force loss compared to CuNiti archwire as shown in table 2 and this is in line with result of a previous study which reported improvement of Niti alloy mechanical properties following the addition of Cu and Co [29]. However, following AC experiment, CuNiti archwires show a high hysteresis percentage that is comparable with Niti archwires and increased compared to other aging conditions. The reason for this increase could be due to significant surface roughness of CuNiti archwires compared to Niti after acidic exposure that lead to binding and friction of the archwires during testing procedure which leads to an increase of the loading force and a decrease of the unloading force. According to current result, PG percentage and gradient of unloading horizontal plateau for CuNiti is less compared to Niti archwire, as shown in load-deflection curves and table 2, which indicate that CuNiti archwire provide more constant force that enables the archwire to work longer thus making frequent reactivation unnecessary [10, 30].

According to these considerations, the archwires should have different indication based on the biomechanical needs. In low friction mechanics, the CuNiti archwires are more appropriate in the alignment stage of moderate to severe crowding, because of their lower forces and superelastic properties in comparison to the conventional Niti. While in high friction mechanics, when a greater friction promoted by the ligation system, these wires may be unable to overcome this resistance particularly for mild crowding cases and Niti archwires would be more suitable. Also Niti archwires are more suitable for correcting derotational and tooth angulation due to their high force level [14].

Regarding the effect of aging conditions on load deflection behaviors of studied archwires, the results showed that the load deflection behavior of Niti archwires did not have a significant difference after in vitro aging compared to as received condition (Figure 4 and Table 3). A study done by Aken et al. [31], which assessed the effect of long term static and repeated deflection on fatigue of superelastic Niti archwires and reported that the unloading force of the Niti and Nitinol superelastic wires was the same with no decrease after both static and repeated deflection at 3mm and this is in line with our result which show that static stress for two months had no significant difference for both Niti and CuNiti archwires compared with as received one. However, no previous study have reported the effect of long term bending deflection on CuNiti archwires.

The hysteresis and plateau gap percentages for Niti archwires did not show any significant difference after two months artificial aging which follows the finding of previous study which revealed that there was no significant statistical difference of plateau gap values among Sentalloy, Truflex and Force I, after one month artificial saliva exposure [20]. However, Kapila et al. [1] in their study revealed that archwires exposed to intra oral aging experienced considerably lower force during unloading as opposed to the as received. This reduction of deactivation mean load compared to our results might be result from additional variables existing in the oral environment, such as oral bacteria [32], galvanic current, electric potential differences, and hydrogen absorption [33].

However, CuNiti archwires have less loading force and a reduced hysteresis after TH compared with WS and AR subgroups. The reason for this result could be a change in the alloy transformation temperature because of dislocations, which were created interface relocation between the martensite and austenite phases upon heating and cooling [34]. This is in accordance with findings of other studies [33-36], that which concluded that thermal cycles increase the temperature of austenite formation and reduce the formation temperature of martensite. Exposure of CuNiti archwires to AC experiment result in increased hysteresis between loading and unloading curves and the reason for this has been explained previously.

CONCLUSION

The conclusions that can be drawn from this study were:

- ✓ CuNiti archwires have more constant and light force compared to Niti archwires of the same size. Thus their usage is differ according to the clinical situations.
- ✓ Niti archwires are more resistant to in vitro- aging than CuNiti archwires.
- ✓ Thermo-cycling reduce the hysteresis percentage while acid challenge increased it for CuNiti archwires.

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Nil.

CONFLICTS OF INTEREST

The authors of this manuscript declare that they have no conflicts of interest, real or perceived, financial or non-financial in this article.

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