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Comparative Evaluation of the Load–Deflection Characteristics of Commercially Available Copper–Nickel–Titanium Orthodontic Archwires: An in Vitro Study

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Abstract:

- ***Background:***

Copper–nickel–titanium (CuNiTi) archwires are widely used during orthodontic alignment because of their superelastic behaviour and favourable force delivery. However, wires with identical nominal dimensions may show substantial differences in mechanical performance. This study evaluated and compared the load–deflection characteristics of six commercially available CuNiTi archwires in 0.014-inch round and 0.014 × 0.025-inch rectangular dimensions.

- ***Materials/Methods:***

An in vitro study evaluated six commercially available CuNiTi archwire brands. Six specimens of each brand were tested in both dimensions. Twenty-five-millimetre wire segments were subjected to a three-point bending test at 37°C using a universal testing machine. Testing followed ISO 15841 principles, with a 14-mm lower support span because of fixture constraints. Wires were deflected to 3.1 mm at 2 mm/min, and force values at 1, 2 and 3 mm deflection were analysed. One-way analysis of variance (ANOVA) followed by Tukey's HSD test was used; $P < 0.05$ was considered statistically significant.

- ***Results:***

All round and rectangular wires demonstrated significant changes in force across the three deflection levels. For round wires, ANOVA was significant for Damon-A ($F = 6.45$, $P = 0.032$), AO-A ($F = 11.53$, $P = 0.009$), Selfy-A ($F = 5.88$, $P = 0.039$), Morelli-A ($F = 62.30$, $P < 0.001$), Dynaflex-A ($F = 36.58$, $P < 0.001$) and Connect-A ($F = 45.26$, $P < 0.001$). Rectangular wires showed larger force increases, with F-values ranging from 26.63 to 156.63 (all $P \leq 0.001$). Morelli-B and Dynaflex-B showed the greatest variation across deflection levels. Tukey analysis demonstrated significant differences across all deflection pairs for most rectangular wires, whereas several round wires showed significance mainly between 1 and 3 mm.

- ***Limitations:***

The investigation was an in vitro three-point bending study and therefore does not reproduce the full complexity of intraoral loading, ligation, thermal cycling, saliva, fatigue or bracket–wire interaction. The modified support span should also be considered when comparing the findings with studies using the standard fixture.

- ***Conclusions/Implications:***

CuNiTi archwires with identical nominal dimensions demonstrated substantial inter-brand differences in load–deflection behaviour. Rectangular wires produced higher forces and steeper force increases than round wires. Independent mechanical characterization may therefore be preferable to reliance on nominal dimensions or manufacturer claims when selecting CuNiTi archwires.

Keywords: *Copper–Nickel–Titanium; CuNiTi; Orthodontic Archwire; Load–Deflection; Three-Point Bending; Superelasticity; Mechanical Properties).*

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I. INTRODUCTION

Orthodontic archwires are the primary active components of fixed appliances and determine the magnitude and manner in which forces are transferred to teeth. Their stiffness, resilience, spring-back and load–deflection characteristics influence the efficiency and biological response to orthodontic tooth movement. Ideally, initial alignment wires should provide relatively light and sustained forces over a useful activation range, while later wires must provide sufficient stiffness for three-dimensional control.[1,6,9]

Nickel–titanium (NiTi) alloys represented a major development in orthodontic wire technology because of their shape memory and superelastic behaviour.[3,4] The reversible austenite–martensite transformation permits large elastic deflections with force delivery over a comparatively broad range. The mechanical response of NiTi wires, however, is influenced by temperature, stress, strain rate, alloy composition and thermomechanical processing.[8,9]

The incorporation of copper into NiTi produced CuNiTi alloys with modified transformation characteristics and reduced hysteresis compared with conventional NiTi.[5,14] Commercial CuNiTi wires have been marketed with different transition temperatures, including approximately 27°C, 35°C and 40°C, allowing manufacturers to target clinically relevant thermal behaviour.[7,14] The clinical performance of a CuNiTi wire is nevertheless determined by more than its nominal alloy designation or dimension.

Load–deflection testing is a useful method for characterizing orthodontic wires because it provides information about resistance to bending and the force generated at defined deflections. Three-point bending has been widely used for comparisons of NiTi and CuNiTi wires under controlled laboratory conditions.[13,19,20,23,26] Differences in wire cross-section also have an important biomechanical effect. Increasing the cross-sectional dimensions, particularly in a rectangular configuration, increases resistance to bending because of the geometric dependence of the moment of inertia.[38,40]

Previous investigations have demonstrated considerable variability between commercially available CuNiTi wires. Pompei-Reynolds and Kanavakis reported interlot variation in transition temperature and unloading force among wires with identical advertised characteristics.[20] Rosen similarly reported significant differences between manufacturers despite comparable dimensions and transition temperatures.[26] More recent work has continued to demonstrate differences in the mechanical behaviour of CuNiTi wires from different manufacturers.[35,36,45] These findings suggest that nominal wire size alone may not predict the force delivered clinically.

Although CuNiTi wires are extensively used for alignment and leveling, comparative data involving multiple brands and both round and rectangular dimensions under the same experimental conditions remain limited. The present study therefore investigated the load– deflection characteristics of six commercially available CuNiTi archwires in 0.014-inch round and 0.014 × 0.025-inch rectangular dimensions. The study was designed to determine whether force delivery differed across deflection levels and to characterize the variability in mechanical response between commercially available products.

II. MATERIALS AND METHODS

Study design and wire specimens: This was an in vitro experimental study of commercially available CuNiTi orthodontic archwires. Six brands were evaluated in two cross-sectional configurations: 0.014-inch round and 0.014 × 0.025-inch rectangular. Six specimens of each brand were tested for each dimension, giving 48 specimens in total. The source document identifies the tested products in the results as Damon (Fig.1), Selfy (Fig.2), Morelli (Fig.3), Connect (Fig.4), AO (Fig.5), and Dynaflex (Fig.6) (as shown in Table 1). The original materials section contains different manufacturer/product names in places; the exact manufacturer-to-product mapping should be verified against the purchase records before submission.

Sample size: The source manuscript reports an a priori calculation using G*Power version 3.1.9.7, with $\alpha = 0.05$ and power = 80%, and a final planned sample of 48 specimens (4 specimens per brand for each of six brands and two wire dimensions). Six specimens per brand and dimension were subsequently described in the materials section. Because the source document contains inconsistent descriptions of the calculation and final sample allocation, the exact sample-size calculation should be checked against the original statistical plan before submission.

Three-point bending test: Mechanical behaviour was evaluated using a three-point bending test based on ISO 15841 for orthodontic wires, with a modified lower support span. A 14-mm support span was used rather than the 10-mm span because of fixture constraints. Wire segments 25 mm in length were prepared from the straightest available distal portion of each preformed archwire. Testing was performed at 37°C to approximate intraoral conditions. Each specimen was mounted centrally and deflected at 2 mm/min to a maximum mid-span deflection of 3.1 mm, followed by unloading. The lower supports were separated by 14 mm and the loading point was centred at 7 mm. Force was continuously recorded by the testing software. Values at 1.0, 2.0 and 3.0 mm deflection were extracted for comparative analysis.

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Statistical analysis: Data were analysed using IBM SPSS Statistics version 26.0. Descriptive data were expressed as mean and standard deviation. The Shapiro–Wilk test was used to assess normality. One-way ANOVA was performed separately for each wire product to compare force values at 1, 2 and 3 mm deflection. When the overall ANOVA was significant, Tukey's honestly significant difference test was used for pairwise comparisons. Mean differences, 95% confidence intervals and adjusted P-values were reported. All tests were two-tailed, and $P < 0.05$ was considered statistically significant.

Ethics statement: Ethics approval was not required for this laboratory study because it involved commercially available orthodontic wires and did not involve human participants, animals or identifiable patient data. Institutional requirements should be confirmed and the statement amended if the approving institution requires documentation.



Fig 1 Ormco 0.014 Inch and 0.014*0.025 Inch


Fig 2 North American Braces 0.014 Inch and 0.014*0.025 Inch



Fig 3 Morelli 0.014 Inch and 0.014*0.025



Fig 4 Connect 0.014 Inch and 0.014*0.025 Inch

III. RESULTS

All tested products showed an increase in force as deflection increased from 1 to 3 mm. The magnitude and statistical pattern of this increase differed between brands and between round and rectangular cross-sections.

ANOVA showed significant differences across the three deflection levels for every round product. Morelli-A had the largest F-value (62.30), followed by Connect-A (45.26) and Dynaflex-A (36.58). Tukey comparisons showed that Damon-A, AO-A and Selfy-A had statistically significant differences primarily between 1 and 3 mm, whereas Morelli-A, Dynaflex-A and Connect-A showed significant differences for all three pairwise comparisons.

All rectangular products showed highly significant differences across deflection levels. Morelli-B and Dynaflex-B demonstrated the largest F-values, 156.63 and 152.51, respectively. Tukey comparisons were significant for all deflection pairs in Damon-B, AO-B, Connect-B, Morelli-B and Dynaflex-B. For Selfy-B, the 1-to-2 mm comparison approached but did not reach significance (mean difference 5.08; 95% CI −0.02 to 10.18; $P = 0.051$), whereas comparisons involving 3 mm were significant.

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Fig 5 American Orthodontics 0.014 Inch and 0.014*0.025 Inch



Fig 6 Dynaflex 0.014 Inch and 0.014*0.025 Inch

Table 1 List of Different Manufacturers Showing the Wire Dimensions

MANUFACTURER	WIRE	SIZE (ROUND WIRE)	RECTANGULAR WIRE
Ormco	CuNiTi	0.014	0.014 * 0.025
American Orthodontics	CuNiTi	0.014	0.014 * 0.025
Orthosystems	CuNiTi	0.014	0.014 * 0.025
North American braces	CuNiTi	0.014	0.014 * 0.025
Dynaflex	CuNiTi	0.014	0.014 * 0.025
Morelli	CuNiTi	0.014	0.014 * 0.025

Table 2 Round 0.014-Inch Wires

Product	1 mm, mean ± SD	2 mm, mean ± SD	3 mm, mean ± SD	F	P
Damon-A	4.33 ± 3.70	9.79 ± 3.99	14.33 ± 2.33	6.45	0.032
AO-A	2.92 ± 2.25	8.54 ± 3.37	13.17 ± 2.04	11.53	0.009
Selfy-A	1.38 ± 0.33	3.12 ± 1.54	4.92 ± 1.53	5.88	0.039
Morelli-A	2.62 ± 1.39	7.58 ± 0.76	12.40 ± 0.96	62.30	<0.001
Dynaflex-A	3.83 ± 1.81	8.88 ± 1.39	13.21 ± 0.44	36.58	<0.001
Connect-A	4.71 ± 0.51	9.00 ± 0.87	13.75 ± 1.75	45.26	<0.001

Table 3 Rectangular 0.014 × 0.025-Inch Wires

Product	1 mm, mean ± SD	2 mm, mean ± SD	3 mm, mean ± SD	F	P
Damon-B	6.17 ± 1.68	16.00 ± 2.38	29.83 ± 1.80	108.18	<0.001
AO-B	6.96 ± 2.93	17.08 ± 3.65	28.21 ± 1.54	41.87	<0.001
Connect-B	4.54 ± 2.19	13.00 ± 1.96	20.79 ± 1.37	56.48	<0.001
Selfy-B	2.08 ± 0.56	7.17 ± 1.04	14.17 ± 3.32	26.63	0.001
Morelli-B	3.12 ± 0.50	14.88 ± 2.25	26.38 ± 1.56	156.63	<0.001
Dynaflex-B	6.29 ± 1.16	17.42 ± 0.14	29.21 ± 2.53	152.51	<0.001

IV. DISCUSSION

The present study demonstrated substantial differences in the load–deflection response of commercially available CuNiTi archwires despite standardized nominal dimensions. All products showed increasing force with increasing deflection, but the magnitude and pattern of the increase differed between brands. These findings support previous reports that CuNiTi wires cannot be assumed to have identical mechanical properties solely because they share the same advertised alloy and dimensions.[20,26,45]

For the 0.014-inch round wires, the mean force increased progressively from 1 to 3 mm in every product. Damon-A, AO-A and Selfy-A showed significant differences mainly between the lowest and highest deflections, whereas Morelli-A, Dynaflex-A and Connect-A showed significant differences between every pair of deflection levels. The latter pattern indicates a more pronounced increase in force

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throughout the tested range. The present data do not permit direct identification of the metallurgical cause, but differences in transformation characteristics, copper content and thermomechanical processing are plausible explanations based on previous literature.[14,20,45]

The clinically relevant issue is not simply whether force increases with activation, but how rapidly force rises over the activation range. A relatively gradual force increase may be desirable during initial alignment, when light and continuous forces are generally sought.[10,12]

Conversely, a very steep response may increase the force delivered to displaced teeth as activation increases. The present results therefore suggest that nominal diameter should not be the only consideration when selecting a 0.014-inch CuNiTi archwire.

The rectangular wires produced substantially greater force values than the round wires at corresponding deflections. This is consistent with basic beam mechanics: bending resistance depends strongly on cross-sectional geometry, and the second moment of area increases markedly when material is distributed farther from the neutral axis.[38,40] Previous experimental work has similarly shown higher force levels from rectangular compared with round orthodontic wires.[13,25] The present study extends this observation to a group of commercially available CuNiTi rectangular wires tested under the same laboratory conditions.

Among the rectangular products, Morelli-B and Dynaflex-B showed the greatest variation across the three deflection levels. Their large mean differences between 1 and 3 mm and significant differences between all pairwise deflections indicate a pronounced force response over the tested range. Damon-B and AO-B also demonstrated strong progressive increases. Selfy-B was distinctive because the 1-to-2 mm comparison narrowly missed statistical significance, while both comparisons involving 3 mm were significant. This suggests that the force response was less pronounced at the lower end of the tested range but increased more clearly at higher deflection.

The findings are consistent with earlier studies showing that increasing wire size and changing cross-sectional form influence force delivery. Major et al. demonstrated that increasing CuNiTi wire size increases force and couple magnitudes but that the increase is not necessarily proportional because of the non-linear behaviour of the alloy.[21] Gatto et al. also demonstrated significant effects of wire dimension on force levels during three-point bending.[19] The current findings similarly indicate that rectangular geometry can substantially alter the force–deflection response.

Variability between brands is also consistent with previous CuNiTi research. Pompei-Reynolds and Kanavakis reported interlot differences in transition temperature and unloading force, even among wires with the same advertised characteristics.[20] Rosen found significant differences in force levels between manufacturers for round and rectangular CuNiTi wires at comparable dimensions and transition temperatures.[26] Gonzaga et al. subsequently reported that CuNiTi wires marketed with the same transition temperature may still demonstrate different force levels and curve characteristics.[45] Together, these studies and the present results indicate that manufacturing history and material processing can be clinically relevant sources of variability.

The mechanical behaviour observed in this study should nevertheless be interpreted cautiously. A three-point bending test isolates wire bending behaviour and does not reproduce the complete orthodontic environment. Bracket slot dimensions, ligation, friction, inter-bracket distance, arch form, tooth position, saliva, temperature fluctuations and repeated loading can all modify the force actually delivered to teeth. Previous studies have shown that fatigue and thermocycling can also alter CuNiTi force characteristics.[24] The modified 14-mm support span used in the present study is another methodological consideration and should be taken into account when comparing absolute force values with studies using different fixture geometries.

An additional limitation is that the study focused on force values at three selected deflections rather than fully modelling the loading and unloading curves or calculating plateau length and hysteresis for every product. Although the source methodology indicates that both loading and unloading were recorded, the reported comparative results primarily present force values at 1, 2 and 3 mm. Future studies should report loading and unloading curves separately, quantify plateau force and plateau length, and document transformation temperatures and alloy composition wherever possible.

From a clinical perspective, the findings reinforce the need for evidence-based wire selection. Round 0.014-inch CuNiTi wires are commonly used during initial alignment, where controlled and relatively light force delivery is desirable. Rectangular wires, by virtue of their greater bending resistance, may be more appropriate when greater stiffness and three-dimensional control are required. However, the present study does not establish clinical superiority of any individual brand because it was an in vitro mechanical investigation. Clinical recommendations should therefore remain linked to the specific treatment objective and the force characteristics documented for the selected wire.

Overall, the results indicate that CuNiTi archwires should not be treated as mechanically interchangeable products. Independent testing, standardized reporting of transformation characteristics and improved manufacturing quality control may help reduce variability and allow clinicians to make more predictable choices.

V. LIMITATIONS

- Only two wire dimensions and six commercially available products were evaluated.
- The experiment used a three-point bending configuration and therefore did not reproduce bracket–wire interaction or the full intraoral environment.
- Testing was performed at a single temperature of 37°C and did not evaluate thermal cycling or fatigue.

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- The modified support span differs from the standard configuration described in ISO 15841 and should be considered when comparing absolute force values.
- Transformation temperatures and detailed alloy compositions were not independently measured in the reported experiment.

VI. CONCLUSIONS

- All tested products showed increasing force with increasing deflection from 1 to 3 mm.
- Rectangular 0.014 × 0.025-inch wires produced higher forces and steeper load–deflection responses than 0.014-inch round wires.
- The magnitude and pattern of force increase differed substantially between brands, suggesting that nominal dimensions alone do not fully describe mechanical performance.
- Independent mechanical characterization and improved standardization may facilitate more predictable evidence-based selection of CuNiTi archwires.

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