Original Article

Flexural properties of rectangular nickel-titanium orthodontic wires when used as ribbon archwires

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ABSTRACT

Objective: To compare the flexural properties of rectangular nickel-titanium (Ni-Ti) orthodontic wires in occlusoapical and faciolingual orientations using a standardized test method.

Materials and Methods: Twenty-two rectangular Ni-Ti wire groups were tested in occlusoapical (ribbon) orientation: eight conventional Ni-Ti products, five superelastic Ni-Ti products, and nine thermal Ni-Ti products ($n = 10$ per group). Six products of thermal Ni-Ti wire were tested in faciolingual (edgewise) orientation. A three-point bending test was performed to measure deactivation force at 3.0-, 2.0-, 1.0-, and 0.5-mm deflections of each rectangular wire at $37.0 \pm 0.5°C$. Analysis of variance and post hoc Student-Newman-Keuls tests were used to compare the mean values of the different groups ($\alpha = .05$).

Results: The ranges of deactivation forces varied greatly with different kinds, sizes, products, and deflections of Ni-Ti wires. One product of conventional and superelastic Ni-Ti wires had steeper force-deflection curves. Four products had similarly shaped flat force-deflection curves, whereas the sixth product had a moderately steep force-deflection curve. Thermal Ni-Ti wires had smaller deactivation forces ranging from 0.773 N (78.8 g) to 2.475 N (252.4 g) between deflections of 1.0 and 0.5 mm, whereas wider ranges of force from 3.371 N (343.7 g) to 9.343 N (952.7 g) were predominantly found among conventional Ni-Ti wires between deflections of 3.0 and 2.0 mm.

Conclusions: Clinicians should critically select archwires for use in the occlusoapical orientation not only based on Ni-Ti wire type, size (0.022×0.016-in or 0.025×0.017-in), and product but also with deactivation deflections from 0.5 and 1.0 mm to obtain light forces in the occlusoapical orientation. (*Angle Orthod.* 2019;89:54–63.)

KEY WORDS: Conventional Ni-Ti; Superelastic Ni-Ti; Thermal Ni-Ti; Copper Ni-Ti; Ribbon archwires; Edgewise archwires

INTRODUCTION

The introduction of nickel-titanium (Ni-Ti) wires revolutionized the field of orthodontics by delivering light, continuous forces over a wider range of displacements.[1–4] Ni-Ti wires have three subdivisions: conventional (nonsuperelastic), superelastic, and thermal (shape memory).[5,6] With the newest, less-stiff Ni-Ti

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Accepted: March 2018. Submitted: February 2017.
Published Online: August 3, 2018

Table 1. Rectangular Ni-Ti Orthodontic Arch Wires of Different Sizes and Products Examined in the Present Study[a]

Wire Code	Size (inches) and Product Name	Manufacturer (Abbreviation)
3MU-2216CL	0.022 × 0.016 Nitinol Classic	3M Unitek, USA (3MU)
3MU-2517CL	0.025 × 0.017 Nitinol Classic	3M Unitek, USA (3MU)
GAC-2216CL	0.022 × 0.016 Lowland Ni-Ti	Dentsply GAC, USA (GAC)
GAC-2517CL	0.025 × 0.017 Lowland Ni-Ti	Dentsply GAC, USA (GAC)
ORM-2216CL	0.022 × 0.016 Ni-Ti	Ormco, USA (ORM)
ORM-2517CL	0.025 × 0.017 Ni-Ti	Ormco, USA (ORM)
RMO-2216CL	0.022 × 0.016 Bio-Lastic	Rocky Mountain Orthodontics, USA (RMO)
RMO-2517CL	0.025 × 0.017 Bio-Lastic	Rocky Mountain Orthodontics, USA (RMO)
CH2-2514HA	0.025 × 0.014 Copper Ni-Ti27	IMD Medical Inc, China (CH2)
CH2-2216HA	0.022 × 0.016 Copper Ni-Ti35	IMD Medical Inc, China (CH2)
CH2-2517HA	0.025 × 0.017 Copper Ni-Ti35	IMD Medical Inc, China(CH2)
ORM-2514HA	0.025 × 0.014 Damon Copper Ni-Ti27	Ormco, USA (ORM)
ORM2216HA	0.022 × 0.016 Copper Ni-Ti35	Ormco, USA (ORM)
ORM-2517HA	0.025 × 0.017 Copper Ni-Ti35	Ormco, USA (ORM)
RMO-2514HA	0.025 × 0.014 FLI Copper Ni-Ti27	Rocky Mountain Orthodontics, USA (RMO)
RMO-2216HA	0.022 × 0.016 FLI Copper Ni-Ti35	Rocky Mountain Orthodontics, USA (RMO)
RMO-2517HA	0.025 × 0.017 FLI Copper Ni-Ti35	Rocky Mountain Orthodontics, USA (RMO)
3MU-2514SE	0.025 × 0.014 Nitinol SuperElastic	3M Unitek, USA (3MU)
3MU-2216SE	0.022 × 0.016 Nitinol SuperElastic	3M Unitek, USA (3MU)
3MU-2517SE	0.025 × 0.017 Nitinol SuperElastic	3M Unitek, USA (3MU)
CH1-2216SE	0.022 × 0.016 SuperElastic	Grikin, China (CH1)
CH1-2517SE	0.025 × 0.017 SuperElastic	Grikin, China (CH1)

[a] CL indicates the conventional Ni-Ti wire; HA, thermal Ni-Ti wire; SE, superelastic Ni-Ti wire.

wire compositions, practitioners can engage wires of larger and rectangular cross sections earlier during active treatment.[7–9]

Rectangular wires have the greatest flexibility in the thickness plane[2]; bending theory permits differentiation between the faciolingual and occlusoapical orientation responses of rectangular wires. The ribbon arch appliance was the first orthodontic appliance with the capacity for full three-axis control of tooth movement.[10,11] Similar occlusoapical brackets have now been incorporated into lingual brackets that open vertically.[12] Numerous studies have compared the flexural characteristics of wires of varying cross-sectional sizes, in the plane of the thickness of a rectangular wire, corresponding to occlusoapical orientation in an edgewise slot. There is a concern, however, about the deflection force when a rectangular Ni-Ti wire is used in the occlusoapical orientation, similar to the force in the faciolingual orientation when a rectangular wire is engaged in an edgewise slot. This study investigated the flexural properties of conventional, superelastic, and thermal Ni-Ti archwires in occlusoapical orientation and thermal Ni-Ti archwires in faciolingual orientation, using a standardized test method.

MATERIALS AND METHODS

A total of 280 rectangular Ni-Ti wire specimens were tested in this study: 10 specimens each of 28 combinations of wire types, sizes, and product names (Table 1). Of the 22 ribbon archwire combinations tested, eight were conventional, five were superelastic, and the remaining nine were thermal. Six groups of thermal Ni-Ti wire were tested in edgewise orientation to investigate the interaction between occlusoapical and faciolingual orientations.

Each specimen was 50 mm in length and was cut from the nearly straight, posterior section of standard lower arch forms. The testing was performed as per ANSI/ADA Specification No. 32.[13] A three-point bending test (Figure 1) was performed in a mechanical testing system (model 4468, Instron Corp, Canton, Ohio). The wire specimens were supported at a span length of 12 mm and displaced at the midpoint by a loading ram attached to a 1-kN load cell (model 2525-

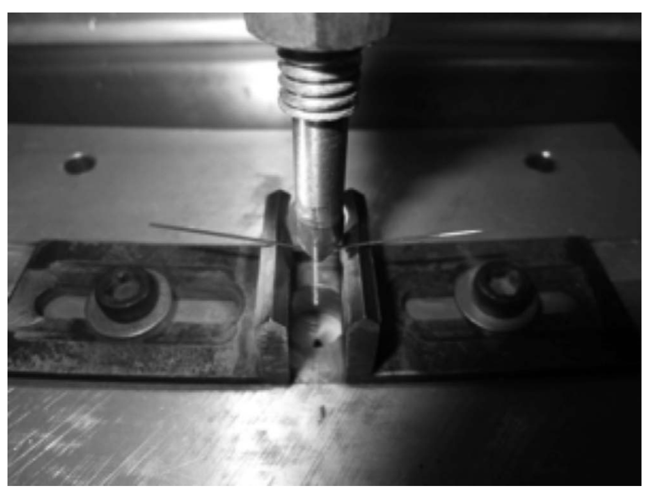

Figure 1. Three-point flexural test apparatus.

Table 2. Mean, Standard Deviation, and Ranking of Load Values in N (g) of Conventional Ni-Ti Archwires of Size 0.025 × 0.017-inch and 0.022 × 0.016-inch at Different Deflections During Unloading in Occlusoapical Orientation[a]

		Load at 3.0-mm UDP			Load at 2.0-mm UDP		
Size (inches)	Product	Mean	SD	SNK	Mean	SD	SNK
0.025 × 0.017	3MU	9.343 (952.7)	0.556 (56.7)	A	7.195 (733.7)	0.200 (20.4)	A
	GAC	8.283 (844.6)	0.295 (30.1)	B	6.299 (642.3)	0.308 (31.4)	B
	ORM	7.043 (718.2)	0.318 (32.4)	C	5.188 (529.0)	0.317 (32.3)	C
	RMO	7.026 (716.4)	0.321 (32.8)	D	4.760 (485.4)	0.176 (17.9)	D
0.022 × 0.016	3MU	6.278 (640.2)	0.339 (34.6)	A	5.157 (525.9)	0.197 (20.0)	A
	GAC	4.985 (508.4)	0.273 (27.8)	B	3.791 (386.6)	0.369 (37.6)	B
	ORM	4.479 (456.7)	0.329 (33.5)	C	3.435 (350.3)	0.098 (9.9)	C
	RMO	4.560 (465.0)	0.251 (25.6)	C	3.371 (343.7)	0.072 (7.3)	C

[a] UDP indicates unloading deflection point; SNK, Student-Newman-Keuls; SD, standard deviation. Within each wire size and product, groups denoted with different capital letters demonstrated different mean deactivation forces ($P < .05$), based on Student-Newman-Keuls post hoc tests.

806, Instron Corp).[14] The wires were tested in occlusoapical orientation under loads applied on the width (larger side) of the rectangular wires. The wires were tested in faciolingual orientation under loads applied on the thickness (smaller side) of the rectangular wire. A linear variable displacement transducer (LVDT model 2600-1063, Instron Corp) was placed in contact with the wire to increase precision of the deflection measurement.[14]

The testing temperature (37°C) was controlled by immersing the test fixture and wire specimen in a temperature-controlled water bath mounted on the base of the mechanical testing system. Water temperature was verified with a thermometer as 37.0 ± 0.5°C.[15,16] The bending test was performed after complete immersion of the wire for 15 minutes to equilibrate its temperature. Each specimen was deflected to 3.1 mm at a crosshead rate of 10 mm/min in conformance with Specification No. 32[13] and then unloaded (deactivated) to the starting displacement of 0 mm. Force and displacement data were collected during loading and unloading (Instron Bluehill®3 software). Force values during deactivation of the wires at 3.0-, 2.0-, 1.0-, and 0.5-mm deflections were calculated. The rationale for the use of the unloading portion of the force-deflection curves was (1) deactivation forces are distributed to teeth by orthodontic wires during treatment and (2) it is stipulated in ANSI/ADA Specification No. 32.[13]

Force values during deactivation were analyzed using three-factor analysis of variance (ANOVA) models that examined wire size, product, and wire orientation to determine differences in mean deactivation force at each deflection and included two-factor ANOVAs for conventional and superelastic wires and a three-factor ANOVA for thermal wires. When interaction was detected, appropriate stratified or group-specific models were performed and post hoc Student-Newman-Keuls tests were conducted using SAS software (v9.3, SAS Institute, Cary, NC). Significance was defined at $\alpha = .05$, and adjustments were made for multiple comparisons in post hoc analyses.

RESULTS

The mean force in Newtons (N) and grams-force (g) of archwires in occlusoapical orientation at each deflection, along with standard deviations and the ranking of forces for conventional Ni-Ti wires of sizes 0.025 × 0.017 inches and 0.022 × 0.016 inches are presented in Table 2. Table 3 summarizes the results of thermal archwires tested in occlusoapical (0.022 × 0.016-inch) and faciolingual (0.016 × 0.022-inch) orientations. Table 4 summarizes the results of thermal archwires tested in occlusoapical (0.025 × 0.017-inch)

Table 3. Mean, Standard Deviation, and Ranking of Load Values in N (g) of Thermal Ni-Ti Archwires at Different Deflections During Unloading in Occlusoapical (0.022 × 0.016-inch) and Faciolingual (0.016 × 0.022-inch) Orientations[a]

		Load at 3.0-mm UDP			Load at 2.0-mm UDP	
Size (inches)	Product	Mean	SD	SNK	Mean	SD
0.022 × 0.016	CH2	4.062 (414.2)	0.095 (9.7)	A	1.752 (178.7)	0.080 (8.2)
	ORM	3.052 (311.2)	0.215 (21.9)	B	1.997 (203.7)	0.191 (19.5)
	RMO	2.773 (282.7)	0.158 (16.1)	C	1.588 (161.9)	0.080 (8.2)
0.016 × 0.022	CH2	2.497 (254.6)	0.065 (6.6)	A	1.368 (139.5)	0.051 (5.2)
	ORM	1.953 (199.2)	0.180 (18.4)	B	1.384 (141.1)	0.159 (16.2)
	RMO	1.691 (172.4)	0.145 (14.8)	C	1.087 (110.8)	0.117 (11.9)

[a] UDP indicates unloading deflection point; SNK, Student-Newman-Keuls; SD, standard deviation. Within each wire size and product, groups denoted with different capital letters demonstrated different mean deactivation forces ($P < .05$), based on Student-Newman-Keuls post hoc tests.

Table 2. Extended

Load at 1.0-mm UDP			Load at 0.5-mm UDP		
Mean	SD	SNK	Mean	SD	SNK
4.411 (449.8)	0.092 (9.4)	B	2.536 (258.6)	0.063 (6.4)	D
5.401 (550.7)	0.252 (25.7)	A	5.169 (527.1)	0.155 (15.8)	A
4.358 (444.4)	0.332 (33.9)	B	3.953 (403.1)	0.516 (52.6)	B
4.134 (421.6)	0.104 (10.6)	C	3.594 (366.5)	0.286 (29.2)	C
3.333 (339.9)	0.119 (12.1)	A	1.979 (201.8)	0.056 (5.7)	C
3.314 (338.0)	0.349 (35.6)	A	3.125 (318.7)	0.419 (42.7)	A
3.048 (310.9)	0.095 (9.7)	B	2.821 (287.7)	0.180 (18.4)	B
3.105 (316.6)	0.057 (5.8)	B	3.232 (329.5)	0.113 (11.5)	A

and faciolingual (0.017 × 0.025-inch) orientations. Table 5 summarizes the results of superelastic archwires in edgewise occlusoapical orientation (0.025 × 0.017-inch and 0.022 × 0.016-inch). The representative force-deflection plots for the three types of Ni-Ti ribbon archwires (Figure 2) show the general characteristics of three 0.022 × 0.016-inch wires. Figure 3 shows unloading values of conventional and superelastic Ni-Ti wires at different deflections in the occlusoapical orientation. Figure 4 shows the mean deactivation forces of thermal Ni-Ti wires at four deflections in both occlusoapical and faciolingual orientations. The unloading values of thermal Ni-Ti wires at 1-mm deflection are presented in Figure 5. 3MU specimens display a force-deflection curve whose "shape" was distinct from the other types in both the superelastic and conventional Ni-Ti wire types. Among the thermal Ni-Ti wire types, some of the CH2 Ni-Ti wires were distinct in terms of the shape of their force-deflection curves.

The ANOVA results (Figures 3 and 4) indicated that, at a given level of deflection, there were statistically significant effects of products and wire sizes in the occlusoapical orientation. Mean forces varied among different sizes, products, and deflections of Ni-Ti wires when tested in the occlusoapical orientation.

A hysteresis behavior was observed in the force-deflection curves of all Ni-Ti ribbon archwires tested. CH2 thermal Ni-Ti wires had larger hysteresis than others (Figure 2). The force-deflection graphs of wires tested in occlusoapical orientation showed superelasticity, except 3MU conventional Ni-Ti, which had plateau regions varying in extent, gradient, and unloading values depending on size, product, and deflection. 3MU conventional and superelastic wires had steeper force-deflection curves compared with the other groups (Figure 2). RMO, ORM, GAC, and CH1 Ni-Ti wires had similar flat force-deflection curves. CH2 thermal Ni-Ti wires represented moderate force-deflection after unloading from 2.0 to 0.5mm.

Thermal Ni-Ti wires had the lowest unloading values among the three Ni-Ti wire types, whereas the superelastic wires showed the highest values in unloading among all Ni-Ti ribbon archwires. Conventional Ni-Ti ranged between the thermal and superelastic Ni-Ti wires. The majority of thermal Ni-Ti wires (Figure 5) had smaller loads at 1.0- to 0.5-mm deflections, whereas higher loads were predominantly found among superelastic and conventional Ni-Ti wires at 3.0- to 2.0-mm deflections (Figure 3).

RMO and ORM Ni-Ti wires had the least significant differences in the conventional Ni-Ti wire groups for most of the deflections. However, both products exhibited significantly different deactivation forces ($P < .001$; Tables 3 and 5) in all deflections of the thermal Ni-Ti wire groups: 1.588 N (161.9 g) for RMO-2216HA

Table 3. Extended

Load at 2.0-mm UDP	Load at 1.0-mm UDP			Load at 0.5-mm UDP		
SNK	Mean	SD	SNK	Mean	SD	SNK
B	1.144 (116.7)	0.070 (7.1)	C	0.907 (92.5)	0.068 (6.9)	C
A	1.615 (164.7)	0.197 (20.1)	A	1.398 (142.5)	0.189 (19.3)	A
C	1.313 (133.9)	0.069 (7.1)	B	1.148 (117.1)	0.077 (7.9)	B
B	0.927 (94.5)	0.056 (5.7)	C	0.817 (83.3)	0.051 (5.2)	C
A	1.271 (129.6)	0.146 (14.9)	A	1.177 (120.0)	0.142 (14.5)	A
C	0.996 (101.6)	0.126 (12.8)	B	0.931 (94.9)	0.124 (12.6)	B

Table 4. Mean, Standard Deviation, and Ranking of Load Values in N (g) of Thermal Ni-Ti Archwires at Different Deflections During Unloading in Occlusoapical (0.025 × 0.017-inch) and Faciolingual (0.017 × 0.025-inch) Orientations[a]

		Load at 3.0-mm UDP			Load at 2.0-mm UDP	
Size (inches)	Product	Mean	SD	SNK	Mean	SD
0.025 × 0.017	CH2	5.342 (544.7)	0.147 (15.0)	A	1.852 (188.9)	0.113 (11.5)
	ORM	4.897 (499.4)	0.163 (16.6)	B	3.196 (325.9)	0.056 (5.7)
	RMO	4.610 (470.1)	0.242 (24.7)	C	2.581 (263.2)	0.201 (20.5)
0.017 × 0.025	CH2	2.843 (289.9)	0.059 (6.0)	A	1.324 (135.0)	0.036 (3.7)
	ORM	2.661 (271.3)	0.137 (14.0)	B	2.043 (208.3)	0.106 (10.8)
	RMO	2.33 (237.6)	0.138 (14.1)	C	1.576 (160.7)	0.140 (14.3)

[a] UDP indicates unloading deflection point; SNK, Student-Newman-Keuls; SD, standard deviation. Within each wire size and product, groups denoted with different capital letters demonstrated different mean deactivation forces ($P < .05$), based on Student-Newman-Keuls post hoc tests.

and 1.997 N (203.7 g) for ORM-2216HA at 2.0-mm deflection in the 0.022 × 0.016-inch Ni-Ti wire groups, and 1.313 N (133.9 g) for RMO-2216HA and 1.615 N (164.7 g) in ORM-2216HA at 1.0-mm deflection in the size 0.022 × 0.016-inch Ni-Ti wire groups. Most of the wire designs were distinctly different from one another ($P < .05$) in the thermal Ni-Ti wire groups, but CH2 thermal Ni-Ti wire consistently exhibited one of the lowest-ranked unloading values at both sizes at deflections of 2.0, 1.0, and 0.5 mm ($P < .05$).

Larger unloading values were measured for most of the larger cross-section wires, except for CH2-2517HA, which produced a mean value of 1.062 N (108.3 g) at 1.0-mm deflection and was lower than the mean value of 1.144 N (116.7 g) for CH2-2216HA at the same deflection. At 0.5-mm deflection, CH2-2517 HA also had a lower mean value of 0.773 N (78.8 g) compared with 0.907 N (92.5 g) for CH2-2216 HA.

Most of the specimens of 0.025 × 0.014-inch Ni-Ti wires could not be analyzed because they became twisted and failed the test before reaching the final activation value of 3.1 mm. This effect was not observed in any of the other archwire sizes.

DISCUSSION

Angle introduced the ribbon arch appliance in 1916.[10] Although both ribbon arch and edgewise appliances had rectangular bracket slots, the principal difference between them was the engagement of rectangular wire in the ribbon arch appliance in the

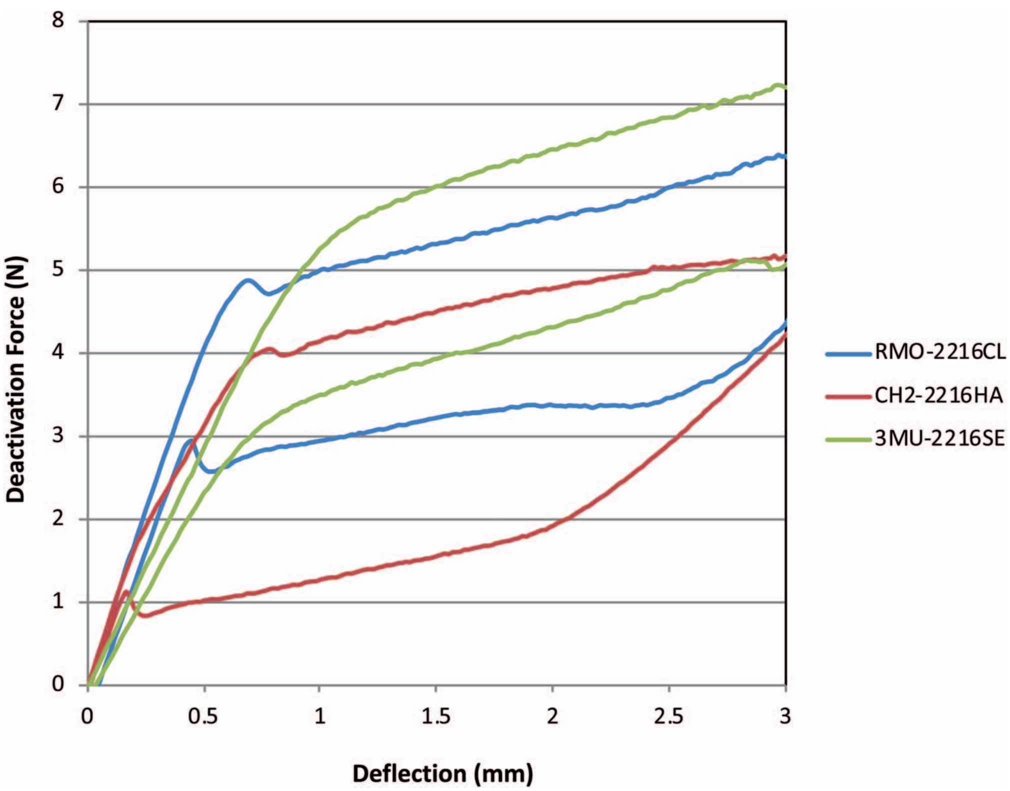

Figure 2. Representative force-deflection plots of three kinds of Ni-Ti archwires in occlusoapical orientation.

Table 4. Extended

Load at 2.0-mm UDP	Load at 1.0-mm UDP			Load at 0.5-mm UDP		
SNK	Mean	SD	SNK	Mean	SD	SNK
C	1.062 (108.3)	0.121 (12.3)	C	0.773 (78.8)	0.129 (13.2)	C
A	2.475 (252.4)	0.075 (7.6)	A	2.121 (216.3)	0.061 (6.2)	A
B	2.002 (204.2)	0.190 (19.3)	B	1.717 (175.1)	0.182 (18.5)	B
C	0.865 (88.2)	0.035 (3.6)	C	0.744 (75.9)	0.038 (3.9)	C
A	1.838 (187.4)	0.105 (10.7)	A	1.706 (174.0)	0.113 (11.5)	A
B	1.415 (144.3)	0.120 (12.2)	B	1.318 (134.4)	0.145 (14.8)	B

slot with its greatest dimension in the occlusoapical orientation. However, in the edgewise appliance, the rectangular wire was inserted into the slot with its greatest dimension in the faciolingual orientation. The ribbon archwire, with its greatest flexibility in the horizontal plane, is actually superior to the edgewise appliance for the rotation and facial-lingual movement of teeth. Unlike ribbon arches in the early stage, which fit accurately into a vertical slot with a matching 0.036 × 0.022-inch dimension stainless steel wire, Schudy and Schudy[17] presented the bimetric appliance by using 90° of twisted 0.016 × 0.022-inch stainless steel archwires to fill the 0.022 × 0.028-inch slots to provide a resilient, gentle, and effective torquing force. The 0.018-inch vertical opened bracket slots positioned anteriorly, such as in Incognito lingual brackets (3M Unitek, Monrovia, Calif),[12] were typically incorporated, with the ribbon archwire becoming more popular in lingual orthodontic treatment.

In occlusoapical appliances, the force from the thickness of a rectangular wire is in the faciolingual orientation and from its width in the occlusoapical orientation. This is the opposite of what occurs with edgewise appliances. The force delivered from the thickness of a rectangular wire differs from that delivered from the width in terms of both force magnitude and direction.

Ni-Ti wires have been developed with greater springback and a larger recoverable energy than stainless steel or beta-titanium wires when activated by the same amount of bending or torquing. Conventional Ni-Ti wire, known as Nitinol Classic (3M Unitek), is a passive martensitic-stabilized alloy and follows Hooke's Law.[18,19] Three of the four conventional Ni-Ti wire products in this study (3MU excluded) exhibited a plateau of constant moment during activation and deactivation. These three wires also demonstrated unexpected superelastic characteristics, showing that superelasticity is one of the most important properties to consider in manufacturing Ni-Ti wires. Superelastic Ni-Ti wire is an austenitic-active alloy, whereas thermal Ni-Ti wire is a martensitic-active alloy.[20] The differences have more to do with the transition temperature range, at room or mouth temperature. Clinically, the thermal Ni-Ti has the distinguishing characteristic of shape memory rather than superelasticity. The distinct superelastic properties of Ni-Ti wires in bending are attributed to a reversible phase transformation between the austenitic form to the martensitic structure of Ni-Ti wires when the wires are subjected to stress or temperature changes.[5,21]

In this study, most of the wires of size 0.025 × 0.014-inch failed during testing and were excluded from analysis because the wires became twisted and slid when deflected by approximately 2.0 mm during the loading process. The reasons were (1) the wire was too narrow in cross section, and when the load increased, the wire became twisted and the loading plane deviated from the center of resistance of the rectangular wire as the wire acquired a rotational moment and slid easily. (2) The smaller contact area between the loading plane and the support decreased the friction between wire plane and support. (3) According to ADA Specification No. 32, the largest deflection for the bending test should be 3.1 mm, which may not be suitable for the 0.025 × 0.014-inch Ni-Ti wire.

The differences in mean unloading forces at specific deflections were important because they allowed for a more straightforward comparison from a clinical standpoint. The results of a two-factor ANOVA for superelastic and conventional Ni-Ti wires indicated that differences existed among wire sizes and products. The results of a three-factor ANOVA for thermal Ni-Ti wires showed that the orientation of rectangular Ni-Ti wires was another important factor related to deactivation. Most specimens with unloading force values less than 1.961 N (200 g) were found among all thermal Ni-Ti wires at a deflection of 1.0 mm. At a deflection of 2.0 mm, only thermal Ni-Ti wires of size 0.022 × 0.016-inch delivered an unloading force value under 1.961 N (200 g), indicating that thermal Ni-Ti wires had lower force values than conventional and

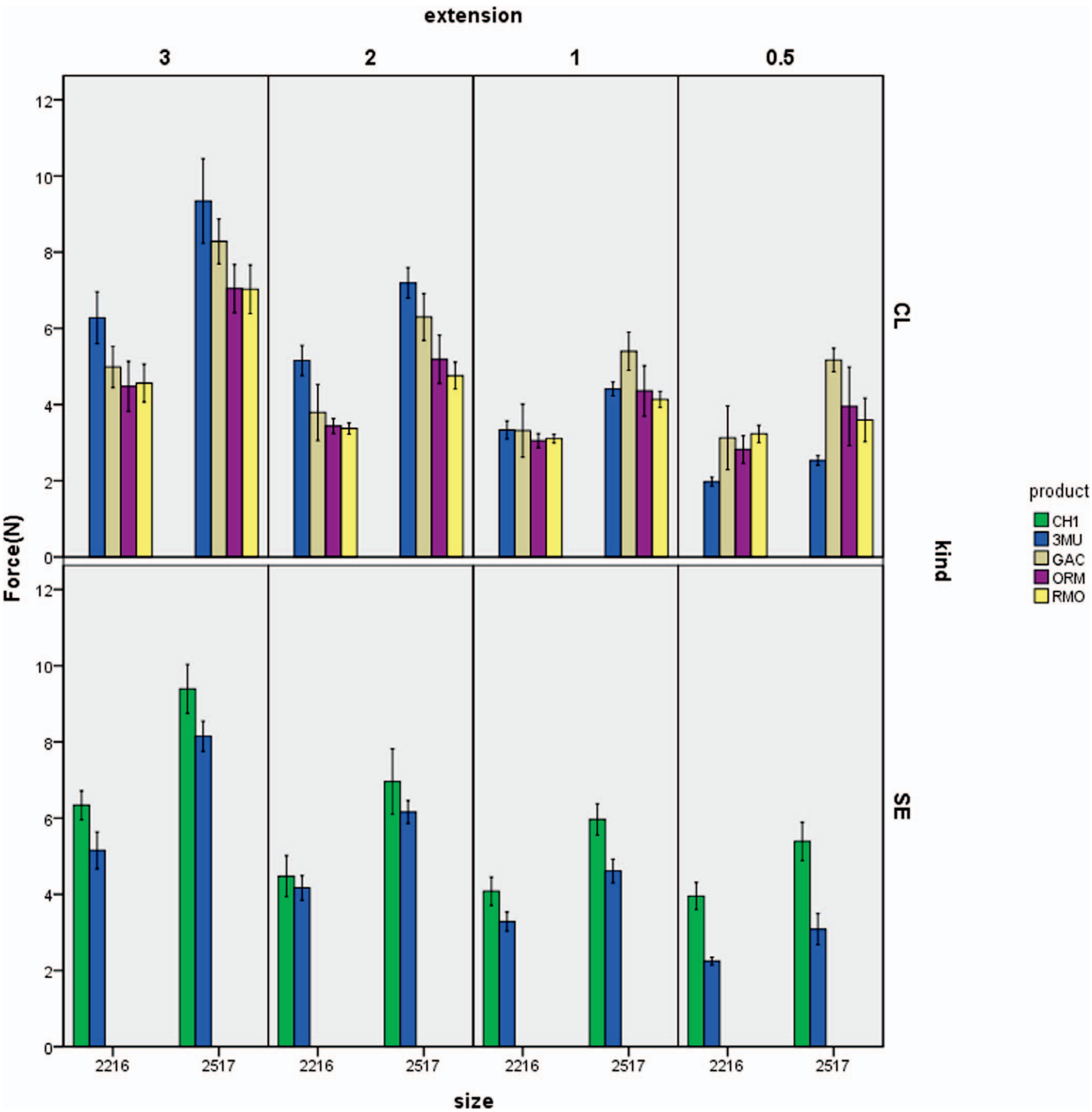

Figure 3. Mean deactivation force values of conventional and superelastic Ni-Ti wires at different deflections as ribbon archwires. The error bars indicate plus and minus one standard deviation from the mean.

Table 5. Mean, Standard Deviation, and Ranking of Load Values in N (g) of Superelastic Ni-Ti Archwires of Size 0.025 × 0.017-inch and 0.022 × 0.016-inch at Different Deflections During Unloading in Occlusoapical Orientation[a]

		Load at 3.0-mm UDP			Load at 2.0-mm UDP
Size (inches)	Product	Mean	SD	*t* Test	Mean
0.025 × 0.017	3MU	8.147 (830.8)	0.198 (20.2)	B	6.162 (628.4)
	CH1	9.392 (957.7)	0.320 (32.6)	A	6.958 (709.5)
0.022 × 0.016	3MU	5.154 (525.5)	0.241 (24.6)	B	4.170 (425.3)
	CH1	6.337 (646.2)	0.193 (19.6)	A	4.475 (456.3)

[a] UDP indicates unloading deflection point; SD, standard deviation. Within each wire size and product, groups denoted with different capital letters demonstrated different mean deactivation forces ($P < .05$), based on Student-Newman-Keuls post hoc tests.

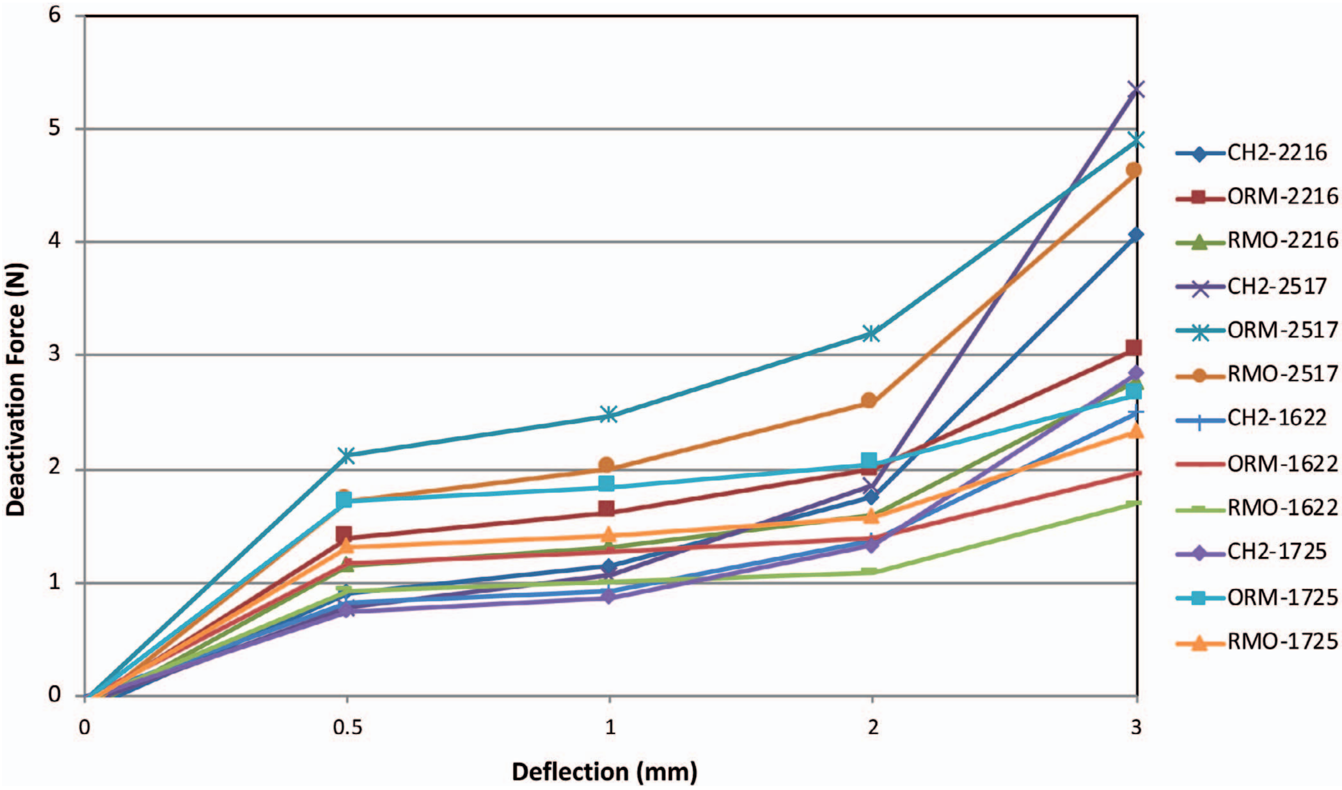

Figure 4. Mean deactivation force values of thermal Ni-Ti wires at different deflections.

superelastic wires in the occlusoapical orientation when used as ribbon archwires.

Theoretically, large cross sections produce larger unloading values than small cross sections. Most of the experimental results from the tests were in good agreement with this theory, except that size 0.025 × 0.017-inch CH2 thermal Ni-Ti wire had a lower unloading value than the size 0.022 × 0.016-inch CH2 thermal Ni-Ti wire in both width and thickness dimensions when deflected to 1.0 and 0.5 mm. The mechanical properties of wires are reported to be very sensitive to slight variations in the manufacturing process; among the more influential parameters, the amount of nickel content, oxygen content, heat treatment, and cold working might account for these differences.

The amount of crowding should be a major consideration in the clinical selection of an orthodontic wire. The differences in the force levels reported in this study, related to the unloading value of rectangular Ni-Ti wires on the width side, will help define and quantify the force of systems biophysically applied to the teeth. As an adjunct to the loading value of rectangular Ni-Ti wires on the thickness side, understanding all such force values would enable clinicians to select the specific rectangular wire that exerts a continuous lower force on teeth in both occlusoapical and faciolingual orientations, using the greater-dimension, rectangular Ni-Ti archwires in the early stages of treatment. Furthermore, by using fewer wires, clinicians can accomplish various tasks simultaneously, such as correction of rotations, tipping, leveling, and torquing.

Table 5. Extended

Load at 2.0-mm UDP		Load at 1.0-mm UDP			Load at 0.5-mm UDP		
SD	*t* Test	Mean	SD	*t* Test	Mean	SD	*t* Test
0.151 (15.4)	B	4.612 (470.3)	0.154 (15.7)	B	3.085 (314.6)	0.206 (21.1)	B
0.431 (43.9)	A	5.966 (608.3)	0.206 (21.0)	A	5.388 (549.4)	0.253 (25.8)	A
0.161 (16.4)	B	3.285 (334.9)	0.125 (12.8)	B	2.246 (229.0)	0.052 (5.3)	B
0.270 (27.6)	A	4.078 (415.8)	0.187 (19.1)	A	3.953 (403.1)	0.179 (18.3)	A

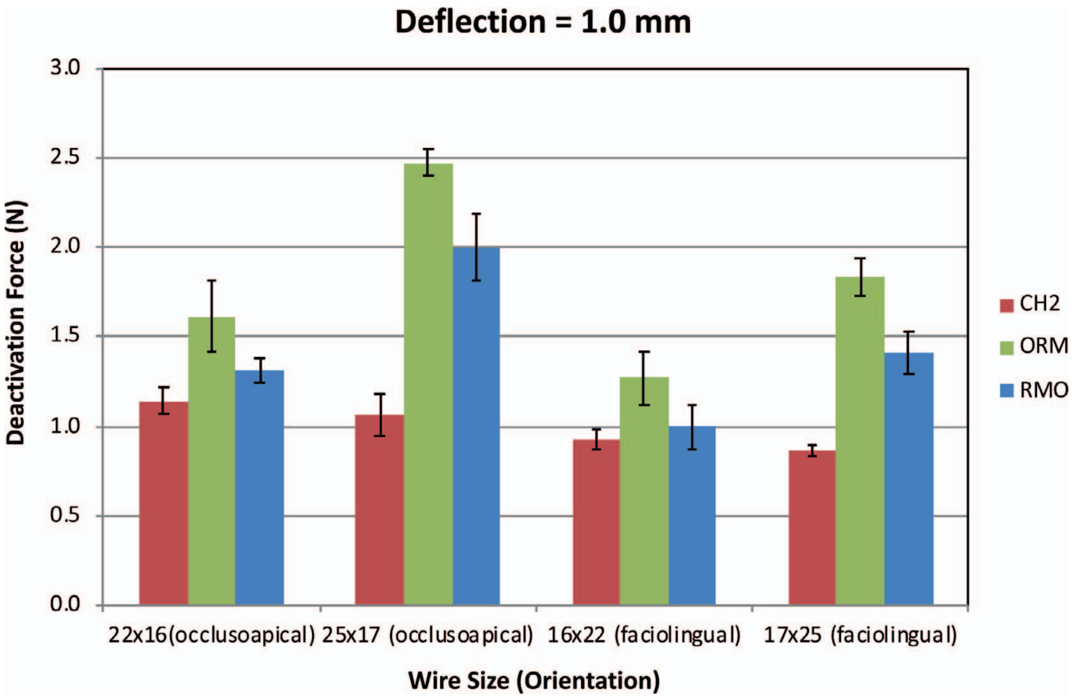

Figure 5. Mean deactivation force values of thermal Ni-Ti wires at 1-mm deflection. The error bars indicate plus and minus one standard deviation from the mean.

Consequently, when using rectangular Ni-Ti wires as ribbon archwires, products should be selected by taking into consideration the severity of the malocclusion in both faciolingual and occlusoapical orientations, as well as the stage of orthodontic treatment in each case. Generally speaking, the lightest, most consistent force that will accomplish the desired tooth movement is the most appropriate force.

CONCLUSIONS

- The ranges of deactivation forces displayed great variation depending on the type, size, product, and unloading deflection of Ni-Ti wires.
- RMO, ORM, GAC, and CH1 ribbon archwire designs have similar force-deflection curves, based on the flat curvilinearity of load values in ribbon archwires.
- The 3MU conventional and superelastic Ni-Ti wires had steeper force-deflection curvilinearity than other groups, whereas CH2 Ni-Ti wires represented moderate steepness of force-deflection curvilinearity at deviations from 2.0 to 0.5 mm.
- The specimens with a smaller deactivation force from 0.773 N (78.8 g) to 2.475 N (252.4 g) between deflections of 1.0 and 0.5 mm were found among thermal Ni-Ti wires, while specimens with wider ranges of force magnitude from 3.371 N (3437 g) to 9.343 N (952.7 g) were predominantly found among conventional Ni-Ti wires between deflections of 3.0 and 2.0 mm.
- To obtain light force in occlusoapical orientation, clinicians should critically select ribbon archwires not only by type (thermal Ni-Ti wire), size (0.022 × 0.016-inch or 0.025 × 0.017-inch), and product (RMO, CH2, or ORM) but also based on deactivation deflections from 1.0 and 0.5 mm.

ACKNOWLEDGMENTS

We gratefully acknowledge the generous support of 3M Unitek Corp (USA), Dentsply GAC (USA), Grikin (China), IMD Medical Inc (China), Ormco Corp (USA), and Rocky Mountain Orthodontics (USA) for their extensive contributions of materials for this study. This study was funded by the Education Department of Fujian Province [2012]128.

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