〔ORIGINAL〕

Bending and torsional properties of commercial nickel-titanium orthodontic wires

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Abstract

The aim of this study was to investigate the force delivery for a variety of types and sizes of commercially available nickel-titanium wires. The relationship of the magnitude of the force and the tooth displacement in a severe crowding case is discussed. Nine brands of nickel-titanium orthodontic wires in a variety of sizes were examined with a three-point bending test and a torsion test at 37℃. Most wires exhibited superelastic behavior for the three-point bending and torsion tests at 37℃. In the three-point bending test, the variation of the average load at 1.5mm deflection during unloading ranged from 0 kgf for Copper Ni-Ti 40℃ with a 0.016×0.022 inch cross-section to 0.46 kgf for ORTHO LINE with a 0.021×0.025 inch cross-section. The average torsion load at a rotation of 30° on deactivation varied from 0 kgf-cm for Copper Ni-Ti 40℃ to 0.023 kgf-cm for ORTHO LINE. The predicted torsional angles for the maxillary arch in the severe crowding case were smaller than expected and only three positions exceeded 20°. Considering the play between bracket slots and archwire, nickel-titanium orthodontic wires of the superelastic type may not exhibit superelastic properties for torsion in most clinical situations.

Key word: Nickel-titanium, Orthodontic wire, Bending, Torsion

1. Introduction

Nickel-titanium wires of near-equiatomic composition were introduced in orthodontic clinical use in 1971 (Andreasen and Hilleman, 1971) and have been popular because of their very low elastic modulus and wide elastic working range (Andreasen and Morrow, 1978 ; Kusy, 1997 ; Brantley, 2001). At present, nickel-titanium wires are available in non-superelastic (Andreasen and Morrow, 1978) and superelastic (Burstone et al., 1985 ; Miura et al., 1986 ; Khier et al., 1991) forms, as well as superelastic products that have shape memory in the oral environment. These wires enable the orthodontic profession to achieve an ideal tooth movement so that the light continuous orthodontic force recommended by Storey and Smith (1952) can be applied.

The mechanical properties of nickel-titanium wires such as bending (Mullins et al. 1996 ; Iijima et al., 2002) and torsion (Øgaard et al., 1994 ; Gurgel et al., 2001) has been studied under in vitro conditions. Nickel-titanium wire is usually selected in the preliminary alignment stages of clinical orthodontics to provide light continuous force. However, the orthodontist must be careful in the selection of arch wires to be able to achieve controlled tooth movement and minimize pathologic repercussions on the teeth. It would be very beneficial for the orthodontist to be able to predict the force delivery of an orthodontic wire depending on wire type, wire size, bracket span, and the condition of the tooth displacement.

The aim of this study was to investigate three-point bending and torsional force delivery for a variety of types and sizes of commercially available nickel-titanium wire. The relationship between the magnitude of force and tooth displacement, in a severe crowding case is discussed.

2. Materials and methods

2.1. Materials

The nine brands of nickel-titanium orthodontic wires and the sizes selected for this investigation are listed in Table1. All types of wire were examined with the three-point bending test but round wires of four sizes were excluded from

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the torsion test. Straight segments of each pre-formed wire in the as-received condition were cut with a water-cooled diamond-saw (Isomet, Buehler, Lake Bluff, IL, USA) into approximately 25 mm length. Particular care was taken when cutting the wire segments to avoid mechanical stress and heating that would alter the proportion of phases in the wire microstructure.

Table 1. Summary of orthodontic wires used in present investigation

Wire brand	Size (inch)	Manufacture
ORTHO LINE Ti-Ni SE 200	0.021×0.025	SHOFU
	0.019×0.025	SHOFU
	0.017×0.025	SHOFU
	0.016×0.022	SHOFU
	φ0.018	SHOFU
	φ0.016	SHOFU
	φ0.014	SHOFU
VIM	φ0.012	Oral Care
Nitinol Classic	0.016×0.022	3M Unitek
Nitinol SE	0.016×0.022	3M Unitek
SENTALLOY	0.016×0.022	TOMY
NEO SENTALLOY	0.016×0.022	TOMY
Ni-Ti	0.016×0.022	Ormco
Copper Ni-Ti 27℃	0.016×0.022	Ormco
Copper Ni-Ti 35℃	0.016×0.022	Ormco
Copper Ni-Ti 40℃	0.016×0.022	Ormco

2.2. Three point bending test

A three-point bending test was carried out for the specimen wires. The span size of the three point bending test,12 mm, was chosen in accordance with ADA Specification No.32 (ANSI/ADA Specification No.32, 2000). All the samples were loaded with the same protocol on a universal testing machine with a20-N load cell (EZ Test, Shimadzu, Kyoto, Japan) at 37℃. The temperature of the laboratory was controlled by heating at ±1℃. Each wire was loaded to a deflection of 3mm (loading process), and then unloaded (unloading process) at a rate of 0.5mm/min. The load was measured at a deflection of 1.5mm during the loading and unloading process ; the mean values and standard deviations (n=5) were calculated.

2.3.Torsional test

The principle of the instrument design for the torsional test is shown in Figure 1. Two diametrically opposed jaws at a fixed distance of 5mm to approximate the inter-bracket distance held the end of the wire. One of the jaws was fixed and a pinion of18mm dia attached to the other jaw was rotated to 90° by pulling the rack attached to the cross-head. After a counter-clockwise rotation of 90° for activation, the deactivation began in a clockwise direction to the original point (0°). The torsional moment generated at activation and deactivation was measured in kgf-centimeters (kgf-cm). The torsional moment at a displacement of 30° during the activation and deactivation process is here determined ; the mean value and standard deviation(n=5) was calculated.

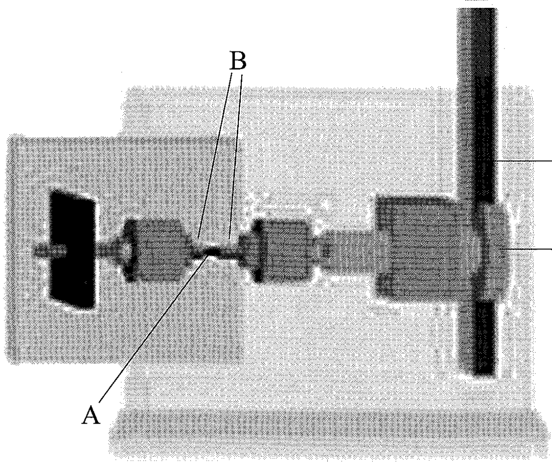

Figure 1. Principles of the instrument design for torsional test. A, Specimen wire ; B, Jaws ; C, pinion ; D, Rack.

2.4. Estimating bending and torsional angles in a case with severe crowding

A subject with severe crowding (Figure 2) was selected from the database at the orthodontic clinic of the Health Sciences University of Hokkaido. The mandibular incisor irregularity index score (Little, 1975) was 12.9, indicating a very severe irregularity, measured to the nearest 0.01 mm on the plaster model with calipers. Pre-adjusted brackets with 0.022 inch slots (Preci Brackets Roth, Shofu, Kyoto, Japan) were bonded to the plaster model and their heights were checked with a height-measuring gauge to ensure ideal positioning. After bonding of all the brackets, the image was saved in the Joint Photographic Experts Group (JPEG) format and analyzed with the use of the image analysis pro-

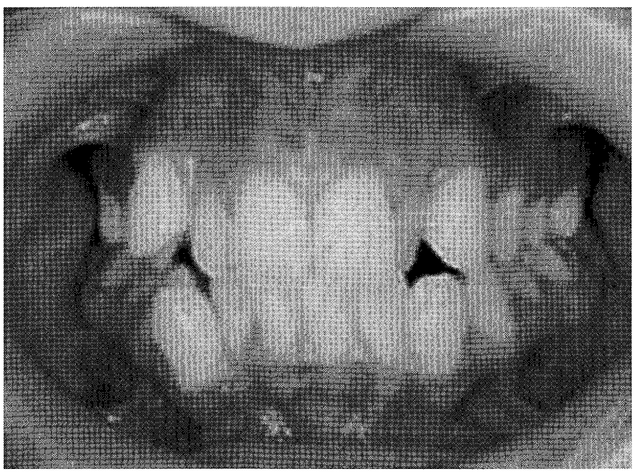

Figure 2. A subject case with severe crowing selected for estimating predicted bending angles and predicted torsional angles.

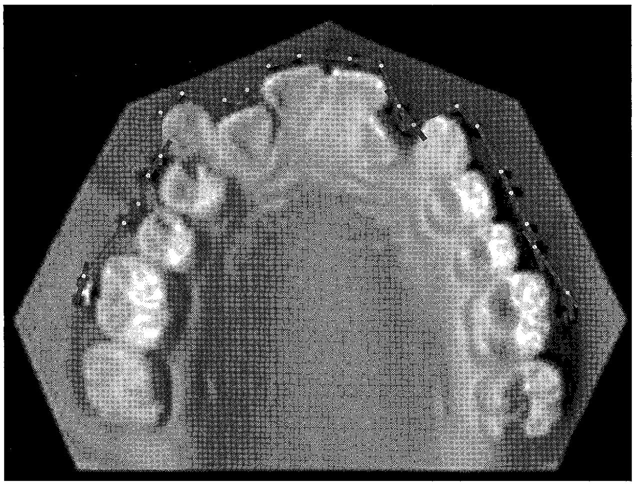

Figure 3. Predicted bending angles when the wire is ligated into bracket slots. The angles of the mesio-distal bracket slot line and the lines through the bracket slots of the adjacent teeth were measured with a protractor.

gram (Adobe Photoshop 6.0, Adobe Systems, Mountain View, CA, USA). The angles of the mesio-distal bracket slot line and the lines through the bracket slots of the adjacent teeth were measured with a protractor (Figure3) ; angles were defined as predicted bending angles when the wire is ligated into the bracket slots. To predict torsional angles, small pieces of full size wires (0.0215×0.028inch) bent to 90° were ligated (Figure4). The torsional angles consisted of a perpendicular line for the occlusal plane and a ligated wire and were measured with a protractor.

3. Results

Figure 5 shows representative load-deflection curves for the nine brands of nickel-titanium orthodontic wires with 0.016×0.022 inch cross-sections. At 37℃, all the wires except Nitinol Classic exhibited superelastic behavior. The average load at 1.5 mm deflection during the loading and unloading are shown in Table 2. The average load at 1.5mm deflection during loading for these wires varied from 0.18 kgf for Copper Ni-Ti 40℃ to 0.52kgf for Nitinol Classic and the average load at 1.5 mm deflection during unloading varied from 0 kgf for Copper Ni-Ti 40℃ to 0.35 kgf for Nitinol Classic.

Figure 6 shows representative load-deflection curves for ORTHO LINE with seven different cross-sectional dimensions and VIM with 0.012 inch round cross-sectional dimensions. The average load at 1.5mm deflection during loading varied from 0.10kgf for VIM with 0.012 round cross-section to 0.89 kgf for the ORTHO LINE with 0.021×0.025 inch cross-section. Also the average load at 1.5 mm deflection during unloading ranged from 0.06 kgf for VIM with 0.012 round cross-section to 0.46 kgf for ORTHO LINE with 0.021×0.025 inch cross-section (Table 2).

Figure 7 shows representative torque-twist curves for the nine 0.016 × 0.022 inch cross-section brands of nickel-titanium orthodontic wires. At 37℃, all the wires except Nitinol Classic exhibited superelastic behavior. The average torsion loads at a rotation of 30° on activation and deactivation are shown in Table 3. The average torsion load on activation at a rotation of 30° for wires with 0.016×0.022 inch cross-sections ranged from 0.005 kgf-cm for Copper Ni-Ti 40℃ to 0.019 kgf-cm for ORTHO LINE. Also, the average torsion load at a rotation of 30° on deactivation ranged from 0 kgf-cm for Copper Ni-Ti 40℃ to 0.011kgf-cm for ORTHO LINE.

Figure 8 shows representative torque-twist curves for ORTHO LINE with 4 different rectangular cross-sectional dimensions. The average torsion load at a rotation of 30° on activation varied with the cross-sectional dimensions (Table

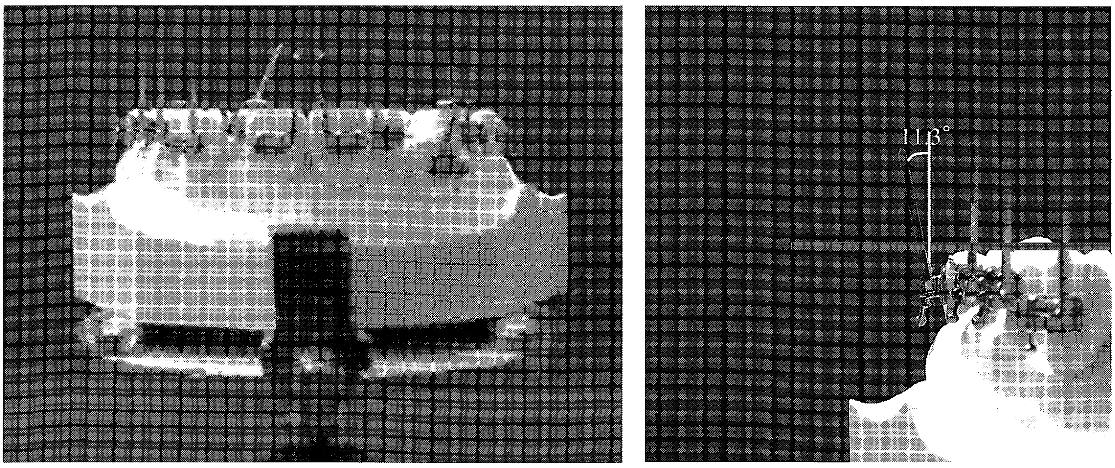

Figure 4. Predicted tosional angles. Small pieces of full size wires (0.0215×0.028inch) bent 90° were ligated. The predicted torsional angles was considered the perpendicular to the occlusal plane and the ligated wire.

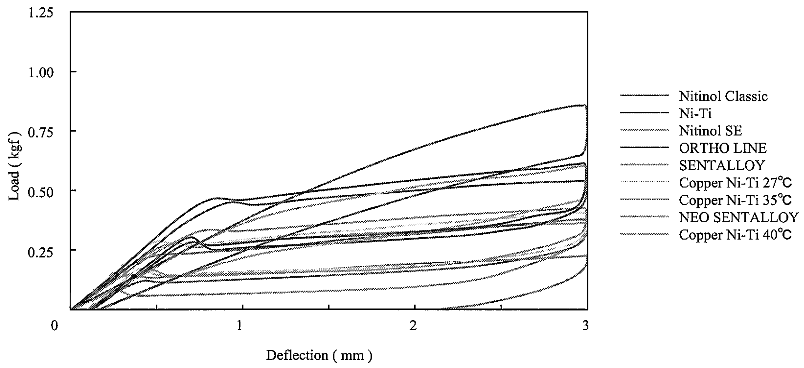

Figure 5. Representative load-deflection curves for nine brands of nickel-titanium orthodontic wires with 0.016×0.022 cross-sections.

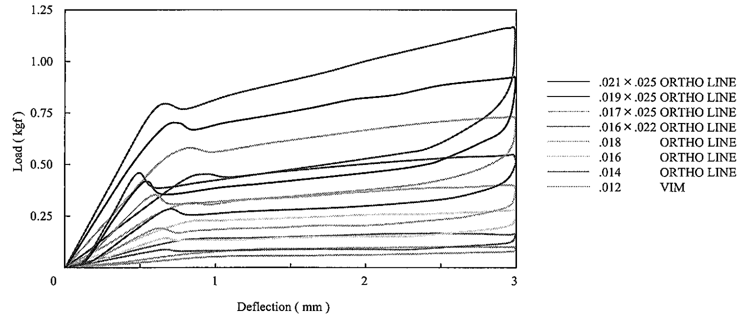

Figure 6. Representative load-deflection curves for ORTHO LINE with 7 different cross-sections and VIM with 0.012inch round cross-section.

Table 2. Average loads at 1.5 mm of deflection for loading and unloading process

Wire brand	Wire size (inch)	Load on loading (kgf)		Load on unloading (kgf)	
		Mean	SD	Mean	SD
ORTHO LINE	0.021 × 0.025	0.89	0.021	0.46	0.019
Ti-Ni SE 200	0.019 × 0.025	0.73	0.033	0.39	0.035
	0.017 × 0.025	0.58	0.033	0.32	0.022
	0.016 × 0.022	0.45	0.033	0.25	0.042
	0.018	0.33	0.028	0.18	0.023
	0.016	0.24	0.007	0.14	0.013
	0.014	0.16	0.006	0.10	0.007
VIM	0.012	0.10	0.003	0.06	0.002
Nitinol Classic	0.016 × 0.022	0.52	0.027	0.35	0.023
Nitinol SE	0.016 × 0.022	0.46	0.007	0.28	0.005
SENTALLOY	0.016 × 0.022	0.35	0.006	0.16	0.005
NEO SENTALLOY	0.016 × 0.022	0.32	0.013	0.08	0.007
Ni-Ti	0.016 × 0.022	0.51	0.004	0.31	0.003
Copper Ni-Ti 27°C	0.016 × 0.022	0.34	0.010	0.18	0.010
Copper Ni-Ti 35°C	0.016 × 0.022	0.29	0.004	0.15	0.004
Copper Ni-Ti 40°C	0.016 × 0.022	0.18	0.005	0.00	0.000

3).

Table 4 shows the predicted bending angles for the maxillary arch when the wire is ligated into bracket slots. As a reference, a 135° predicted bending angle corresponds to 3 mm of three-point bending. The case employed in this study showed that only 5 positions had values of less than 135°. Table 5 shows the predicted torsional angles for the maxillary arch and here only three positions exceed 20°.

4. Discussion

This investigation subjected a variety of commercially available nickel-titanium orthodontic wires to controlled bench-testing with three point bending and a torsional test. The span size of the three point bending test employed in this study was 12 mm, in accordance with the ADA Specification No.32 (ANSI/ADA Specification No.32, 2000) for orthodontic wires. Also, the distance between jaws for the tosion test employed in the present study was 5 mm, simulating the inter-bracket distance in clinical situations. At 37℃, most wires exhibited superelastic behavior, a phenomenon in which the wire exhibits a low continuous force with a plateau during loading and unloading (Burstone et al., 1985 ; Miura et al., 1986). This study also estimated the clinically produced bending angles in a patient with severe crowding. Only 5 positions indicated the predicted bending angle of less than 135°, and a deflection greater than 3 mm in the three-point bending. Six positions showed values between 135° and 157°. Because there is comparatively smaller deflection at the other positions, the superelastic characteristics

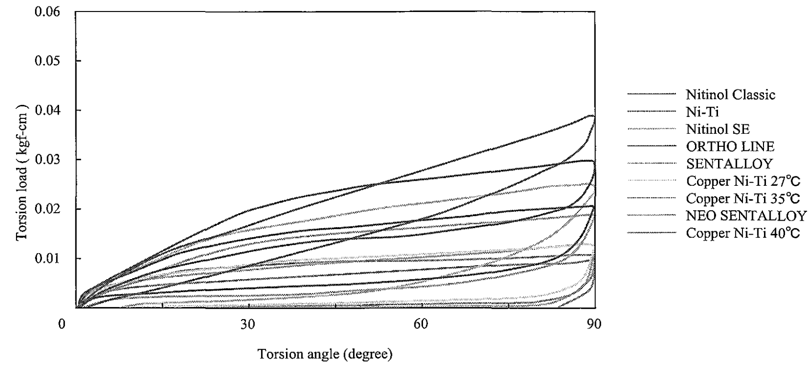

Figure 7. Representative torque-twist curves for the nine brands of nickel-titanium orthodontic wires with 0.016(0.022cross-sections.

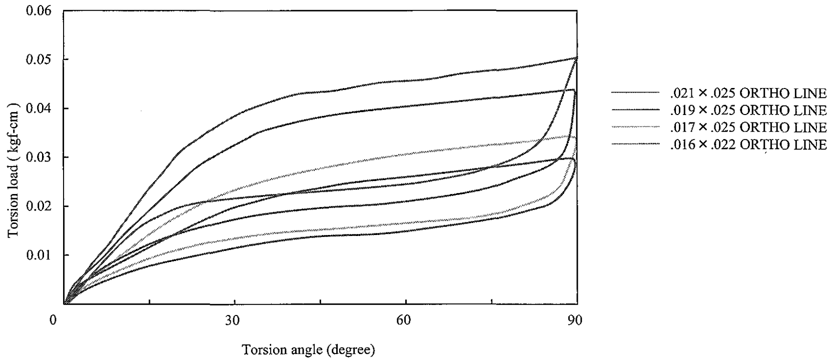

Figure 8. Representative torque-twist curves for ORTHO LINE with 4 different rectangular cross-sections.

Table 3. Average torsion loads at rotation of 30° for activation and deactivation process

Wire brand	Wire size (inch)	Load on activation (kgf-cm)		Load on deactivation (kgf-cm)	
		Mean	SD	Mean	SD
ORTHO LINE	0.021×0.025	0.039	0.001	0.023	0.003
Ti-Ni SE 200	0.019×0.025	0.033	0.001	0.018	0.001
	0.017×0.025	0.024	0.002	0.011	0.002
	0.016×0.022	0.019	0.002	0.011	0.001
Nitinol Classic	0.016×0.022	0.015	0.002	0.009	0.001
Nitinol SE	0.016×0.022	0.015	0.002	0.002	0.002
SENTALLOY	0.016×0.022	0.013	0.001	0.002	0.002
NEO SENTALLOY	0.016×0.022	0.008	0.001	0.000	0.000
Ni-Ti	0.016×0.022	0.014	0.001	0.004	0.001
Copper Ni-Ti 27℃	0.016×0.022	0.009	0.002	0.001	0.001
Copper Ni-Ti 35℃	0.016×0.022	0.009	0.001	0.001	0.001
Copper Ni-Ti 40℃	0.016×0.022	0.005	0.001	0.000	0.000

of wires like the ones tested here may not be a fact of in other positions in bending. The variation in the average load at 1.5mm deflection during unloading, a clinically important parameter, ranged from 0 kgf for Copper Ni-Ti 40℃ with 0.016x0.022 inch cross-section to 0.46 kgf for ORTHO LINE with 0.021x0.025 inch cross-section. Even with the same wire dimensions, the wires produced different average forces. The reason for this is that the wires have different transformation temperatures, affected by the alloy composition, heat treatment, and work hardening during the wire drawing process (Brantley, 2001). Here Copper Ni-Ti 40℃ produced a 0g load as Copper Ni-Ti has a transformation temperature (Austenite-Finish Temperature : temperature at which the metallurgical transformation of a shape-memory wire, from its low-temperature phase (s) to its high-temperature phase, is completed) higher than the intraoral temperature (Brantley, 2001). Since mechanical properties such as superelasticity and shape memory of nickel-titanium orthodontic wire show exceptional temperature-sensitivity, the mechanical property changes with temperature conditions has been studied (Mullins et al., 1996 ; Iijima et al., 2002).

The optimum force necessary for physiologic tooth movement has long been a matted of debate and there is no consensus at the present time. However, the average load above 200g at 1.5mm deflection during unloading in this study may be considered a heavy force (Chan and Darendeliler, 2005). Heavy forces lead to necrosis of the periodontal ligament, rapidly developing pain, and undermining resorption of the alveolar bone near the affected tooth (William and Henry, 2000). In dog experiments, light forces resulted in a smaller hyalinized zone on the pressure sides (Reitan, 1964). It has also been reported that there is more resorption of the root surface with heavier forces than with lighter forces (Chan and Darendeliler, 2005). Although the magnitude of a

Table 4. Predicted bending angle for the maxillary arch

	Site	Left side (degree)	Right side (degree)
Central incisor	Mesial	171	158
	Distal	126	149
Lateral incisor	Mesial	166	156
	Distal	103	147
Canine	Mesial	111	129
	Distal	162	132
First premolar	Mesial	178	148
	Distal	178	167
Second premolar	Mesial	172	162
	Distal	162	179
First molar	Mesial	155	157

Table 5. Predicted torsional angle for the maxillary arch

	Left side (degree)	Right side (degree)
Central incisor	6.1	1.1
Lateral incisor	27.6	12.2
Canine	3.7	23.1
First premolar	1.3	5.7
Second premolar	2.7	9.5
First molar	11.3	20.8

force may be temporarily increased by changing the oral temperature, Shape-Memory wire (which can be bent or twisted without fracture at low temperatures, but assumes a pre-set configuration upon heating above the austenite-finish temperature) has clinical advantages (Mullins et al.,1996) because it is easy to ligate archwire to severely malposed teeth.

On the other hand, the predicted torsional angles for the maxillary arch were smaller than expected ; only three positions exceeded 20°. Also, orthodontic wires have edge bevels that significantly influence the torsional clearance (Sebanc et al., 1984 ; Meling et al., 1997). Because the amount of torsional clearance between the wire and bracket depends on the slot height and the wire dimensions, as well as the degree of wire rounding (Meling et al., 1993), an undersized wire should result in a poorer fit in the bracket slot and may lead to less control during tooth movement. A previous study reported that the mean torsional play of the 0.016× 0.022 inch wire and 0.018×0.025 inch cross-section wires with 0.018 inch brackets were 17.5° and 4.8°, respectively (Meling et al., 1993). Therefore, nickel-titanium orthodontic wires may not exhibit superelastic properties for torsion in usual clinical situations.

5. Conclusions

Under the conditions of this study, the following conclusions were drawn :

1. The variation in the average load at 1.5 mm deflection during unloading for the three-point bending test ranged from 0 kgf for Copper Ni-Ti 40℃ with 0.016×0.022inch cross-sectional dimensions to 0.46 kgf for ORTHO LINE with 0.021×0.025inch cross-sectional dimensions.
2. The average torsion load at a rotation of 30° on deactivation varied from 0 kgf-cm for Copper Ni-Ti 40℃ with 0.016 ×0.022inch cross-section to 0.023 kgf-cm for ORTHO LINE with 0.021×0.025 inch cross-section.
3. The case employed in this study, had very severe crowding, and showed that 5 positions of the maxillary arch had predicted bending angles, exceeding 3 mm deflection in the load-deflection curves.
4. Nickel-titanium orthodontic wires may not exhibit superelastic properties for torsion in commonly experienced clinical situations.

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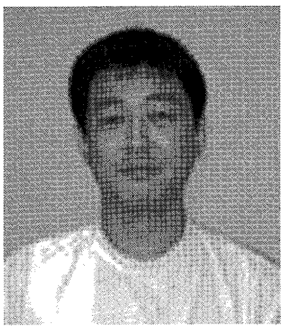

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