

Deactivation force-deflection behavior of multistranded stainless steel wires

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This investigation measured the deactivation (unloading) force-deflection behavior of selected multistranded stainless steel orthodontic wires. The guidelines from the revised American National Standards Institute/American Dental Association Specification No. 32 for orthodontic wires (type 2, nonlinear elasticity) were used to perform a 3-point bending test to obtain data for the deactivation force levels at 3, 2, 1, and 0.5 mm, and permanent deformation values. The study tested 20 wire designs: triple-stranded twisted wires, 5- and 6-stranded coaxial wires, and 8- and 9-stranded braided rectangular wires of selected cross-sections. Twenty specimens were tested for each wire design. The specification guidelines for testing provided a means for obtaining comparative unloading force delivery data for the deflections tested. Multistranded wires of significantly different cross-section, weave, and strand number fell within relatively narrow ranges of force delivery at the 0.5-mm (1.7-42.7 grams-force [gmf]) and 1-mm (31.1-134.2 gmf) deflections and wider ranges of force levels at the 2-mm (57.0-320.5 gmf) and 3-mm (72.5-451.8 gmf) deflections. All wires exhibited some permanent deformation, but none averaged greater than 0.66 mm. The testing also showed that multistranded wires of significantly different design exhibit similar force levels. The guidelines of the revised Specification No. 32 yielded deactivation data with regard to force delivery and provided comparisons of the wire designs tested. (*Am J Orthod Dentofacial Orthop* 2003;124:61-8)

The first stage of orthodontic treatment entails leveling and aligning the teeth. To accomplish this, an appliance that delivers forces that are light and decrease only moderately between appointments is required. The force in play to align and level the teeth is not the activation force but the deactivation force, or unloading force, of the appliance. The activation and deactivation behaviors of a wire might not be the same. Therefore, force-deflection graphs generated during the activation (loading) and deactivation (unloading) cycles of a wire might not superimpose.¹ Knowledge of deactivation behavior is important to the clinician for optimal wire selection. When a clinician engages a wire into the bracket slots of an appliance, energy is stored. Work is done on the dentition during the deactivation of the appliance and is evidenced as tooth movement.² Multistranded wires are commonly used for initial alignment of teeth because they can

deliver the appropriately light forces to the teeth over a significant range of deactivation. These wires also serve as an economical alternative to the more expensive nickel-titanium wires.^{3,4}

The 1977 American Dental Association (ADA) Specification No. 32⁵ that characterized orthodontic wires stipulated collection of information on the activation behavior of wires through use of a cantilever-bending test. Subsequently, a variety of testing methodologies was considered. Testing that reproduced malpositions on simulated dental arches with appliances fixed on them was proposed.⁶ A testing method with brass mandrels of varying slot dimensions on which wires were wound and unwound at uniform speed was also designed.⁷ A possible limitation of the specification was its use of elastic beam theory. For beam theory to be valid, activation of a beam should not exceed one tenth of the beam's length. However, this is not true in clinical situations in which a wire may be deflected more than 10% during the initial leveling and aligning. A change from the existing cantilever test to a 5-point test was then designed to simulate wire engagement onto a single malaligned tooth.⁸

In 1999, the American National Standards Institute (ANSI)/ADA Specification No. 32 for orthodontic wires not containing precious metals⁵ was withdrawn from the Accredited Standards Committee MD156

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Table I. Selected wires

Size (in) and trade name	Vendor*	Weave	No. of strands	Wire code
.015 Wildcat	GAC	Twisted	3	SS015T3
.0175 Wildcat	GAC	Twisted	3	SS0175T3
.0195 Wildcat	GAC	Twisted	3	SS0195T3
.0215 Tripleflex	Ormco	Twisted	3	SS0215T3
.0155 Unitek Twist	Unitek	Coaxial	5	SS0155C5
.0175 Unitek Twist	Unitek	Coaxial	5	SS0175C5
.0195 Unitek Twist	Unitek	Coaxial	5	SS0195C5
.0215 Unitek Twist	Unitek	Coaxial	5	SS0215C5
.0175 Respond	Ormco	Coaxial	6	SS0175C6
.0195 Respond	Ormco	Coaxial	6	SS0195C6
.0215 Respond	Ormco	Coaxial	6	SS0215C6
.016 × .022 D-Rect	Ormco	Braided	8	SS1622B8
.017 × .025 D-Rect	Ormco	Braided	8	SS1725B8
.018 × .025 D-Rect	Ormco	Braided	8	SS1825B8
.019 × .025 D-Rect	Ormco	Braided	8	SS1925B8
.021 × .025 D-Rect	Ormco	Braided	8	SS2125B8
.016 × .022 Force-9	Ormco	Braided	9	SS1622B9
.017 × .025 Force-9	Ormco	Braided	9	SS1725B9
.018 × .025 Force-9	Ormco	Braided	9	SS1825B9
.019 × .025 Force-9	Ormco	Braided	9	SS1925B9

*Vendors listed are located as follows: GAC International, Bohemia, NY; Ormco, Glendora, Calif; 3M Unitek, Monrovia, Calif.

working group as outdated. Development of a revised specification with an expanded scope then ensued. The revised ANSI/ADA Specification No. 32,⁹ approved by the ADA and the ANSI, became effective in December 2001. The aim of this study was to use some guidelines of this newly adopted specification to obtain deactivation force-deflection data for selected multistranded stainless steel orthodontic wires.

MATERIAL AND METHODS

A total of 400 specimens were tested—20 specimens each of 20 designs. Three different kinds of weaves of wires were included in the sample. The round wires were twisted and coaxial, and the rectangular wires were braided. Table I lists the wires that were tested. A nomenclature was devised to identify the wires being tested. Alloy, size, weave, and number of strands identified the wires. For example, SS0215T3 denotes a stainless steel wire of .0215-in diameter with a twisted weave and 3 strands. All round wires included a 0 in denoting the diameter (eg, 0215), but the 0 was omitted for the rectangular wires. For example, SS2125B8 refers to a stainless steel wire, .021 × .025 in, with a braided weave and 8 strands.

The test methodology followed that of Specification No. 32, although 20 specimens were tested for each wire design (the specification requires only 10). Preliminary measurements were found to exhibit no direct proportionality between load and deflection for the

wires to be tested; therefore, the wires were deemed to be of the type 2 classification (nonlinear elasticity). They were tested at room temperature because they were stainless steel, and their mechanical properties are not measurably affected by an increase in body temperature, unlike those containing nickel-titanium or copper-nickel-titanium.¹⁰ A 3-point bending test was performed on each wire specimen with a mechanical testing system (Model 4468, Instron, Canton, Mass). Figure 1 shows the 3-point flexural test apparatus. Five-centimeter wire lengths were used, and the span length was 12 mm. Each specimen was deflected to 3.1 mm and deactivated at a crosshead rate of 10 mm/min in conformance with the specification. Although not expressly required by the specification, a linear variable displacement transducer (LVDT Model 2600-1063, Instron) was placed in contact with the wire to increase the precision in measurement of the deflection during deactivation and to ensure that the initial deflection of the wires was the 3.1 mm required. This ensured that the deflections were accurately determined at 3-, 2-, 1-, and 0.5 mm required by the specification. A representative force-deflection plot is given in Figure 2, which shows the general character of the multistranded stainless steel wires tested. The loading (activation) portion of the graph was different from the unloading (deactivation) portion. This hysteresis behavior was observed for all wires tested. Deactivation forces at 3, 2, 1, and 0.5 mm and permanent deformation data were obtained

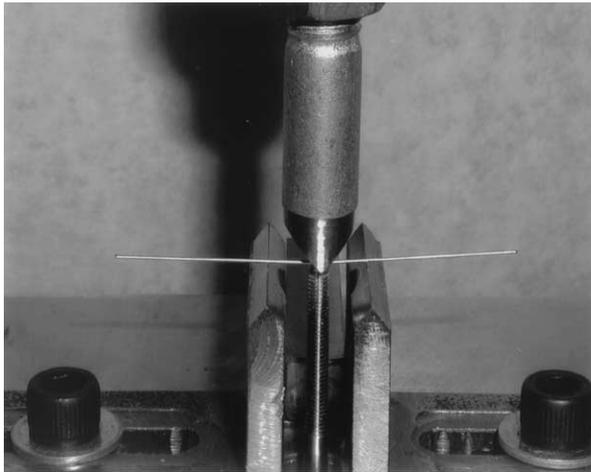
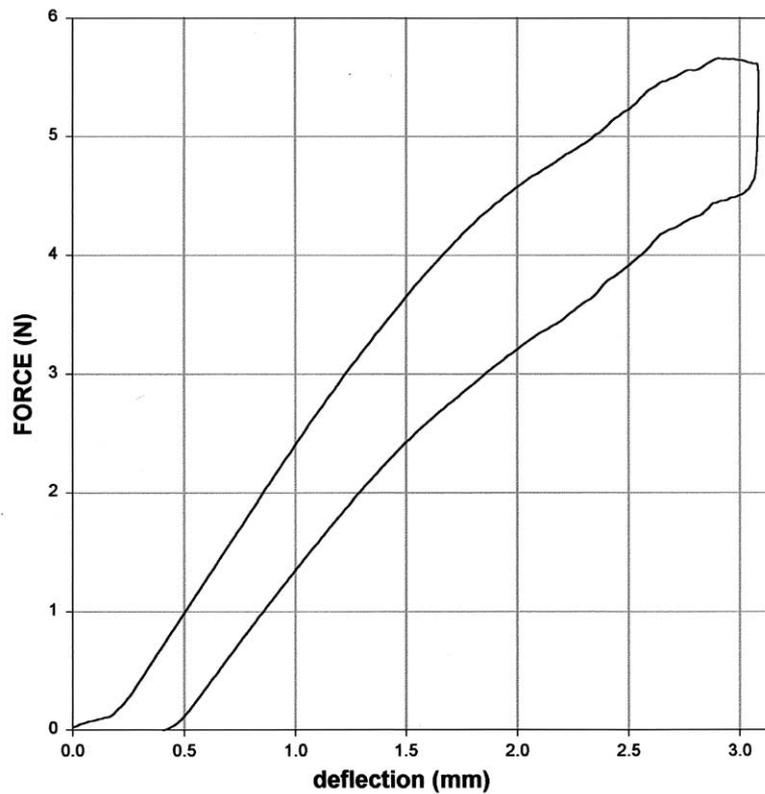


Fig 1. Three-point flexural test apparatus.

from data points that were also used to form means of the plots for the various wire designs. The data points were collected at 10 per second via Instron Series IX software. Descriptive and inferential statistics were performed on the data with SAS software (SAS Institute, Cary, NC). The means and standard deviations for each of the 20 wire groups for the parameters measured (ie, deactivation forces at 3-, 2-, 1-, and 0.5-mm deflections and permanent deformation) were calculated. The data were subjected to analyses by general linear models and post hoc Student-Newman-Keuls (SNK) tests at $\alpha = .05$.

RESULTS

The means and standard deviations for the forces at a given deflection are rank ordered in Tables II, III, IV, and V in newtons (N) and grams-force (gmf), and the permanent deformation values (mm) are shown in Table VI. The conversion factor for changing newtons



Force (3 mm) = 4.43 ± 0.02 N Force (2 mm) = 3.14 ± 0.04 N
Force (1 mm) = 1.32 ± 0.07 N Force (0.5 mm) = 0.12 ± 0.06 N
Permanent Deformation = 0.43 ± 0.02 mm

Fig 2. Representative force-deflection plot.

Table II. Ranking of wires by deactivation force at 3-mm deflection

Wire	Size (in) and trade name	Mean \pm SD N (gmf)	SNK
SS0215T3	.0215 Tripleflex	4.431 \pm 0.031 (451.8 \pm 3.1)	A
SS1825B9	.018 \times .025 Force-9	3.975 \pm 0.066 (405.3 \pm 6.7)	B
SS1925B9	.019 \times .025 Force-9	3.840 \pm 0.078 (391.5 \pm 8.0)	C
SS2125B8	.021 \times .025 D-Rect	3.652 \pm 0.088 (372.4 \pm 9.0)	D
SS1725B9	.017 \times .025 Force-9	2.923 \pm 0.055 (298.1 \pm 5.6)	E
SS1825B8	.018 \times .025 D-Rect	2.810 \pm 0.045 (286.5 \pm 4.6)	F
SS1725B8	.017 \times .025 D-Rect	2.805 \pm 0.046 (286.0 \pm 4.7)	F
SS1925B8	.019 \times .025 D-Rect	2.570 \pm 0.044 (262.1 \pm 4.5)	G
SS0195T3	.0195 Wildcat	2.525 \pm 0.044 (257.5 \pm 4.5)	G
SS0215C6	.0215 Respond	2.430 \pm 0.017 (247.7 \pm 1.8)	H
SS1622B8	.016 \times .022 D-Rect	2.148 \pm 0.031 (219.1 \pm 3.1)	I
SS0215C5	.0215 Unitek Twist	2.084 \pm 0.008 (212.5 \pm 0.8)	J
SS1622B9	.016 \times .022 Force-9	1.964 \pm 0.028 (200.3 \pm 2.8)	K
SS0195C6	.0195 Respond	1.541 \pm 0.004 (157.1 \pm 0.5)	L
SS0175T3	.0175 Wildcat	1.522 \pm 0.007 (155.2 \pm 0.7)	L
SS0195C5	.0195 Unitek Twist	1.499 \pm 0.020 (152.8 \pm 2.1)	L
SS015T3	.015 Wildcat	1.145 \pm 0.001 (116.7 \pm 0.1)	M
SS0175C5	.0175 Unitek Twist	0.932 \pm 0.009 (95.0 \pm 0.9)	N
SS0175C6	.0175 Respond	0.877 \pm 0.005 (89.4 \pm 0.5)	O
SS0155C5	.0155 Unitek Twist	0.712 \pm 0.006 (72.6 \pm 0.7)	P
Mean of all wires @ 3.0 mm		2.319 \pm 1.084 (236.5 \pm 110.56)	

SD, standard deviation; SNK, Student-Newman-Keuls test.

Table III. Ranking of wires by deactivation force at 2-mm deflection

Wire	Size (in) and trade name	Mean \pm SD N (gmf)	SNK
SS0215T3	.0215 Tripleflex	3.143 \pm 0.043 (320.5 \pm 4.3)	A
SS1825B9	.018 \times .025 Force-9	2.641 \pm 0.042 (269.4 \pm 4.3)	B
SS1925B9	.019 \times .025 Force-9	2.499 \pm 0.039 (254.8 \pm 4.0)	C
SS2125B8	.021 \times .025 D-Rect	2.328 \pm 0.046 (237.4 \pm 4.7)	D
SS0195T3	.0195 Wildcat	2.275 \pm 0.021 (232.0 \pm 2.1)	E
SS1725B8	.017 \times .025 D-Rect	2.022 \pm 0.030 (206.2 \pm 3.1)	F
SS1825B8	.018 \times .025 D-Rect	1.956 \pm 0.030 (199.5 \pm 3.0)	G
SS1725B9	.017 \times .025 Force-9	1.830 \pm 0.034 (186.6 \pm 3.4)	H
SS1925B8	.019 \times .025 D-Rect	1.805 \pm 0.027 (184.1 \pm 2.8)	H/I
SS0215C6	.0215 Respond	1.793 \pm 0.026 (182.8 \pm 2.7)	I
SS1622B8	.016 \times .022 D-Rect	1.628 \pm 0.018 (166.0 \pm 1.8)	J
SS0215C5	.0215 Unitek Twist	1.612 \pm 0.018 (164.4 \pm 1.8)	J
SS1622B9	.016 \times .022 Force-9	1.411 \pm 0.016 (143.8 \pm 1.6)	K
SS0175T3	.0175 Wildcat	1.377 \pm 0.016 (140.4 \pm 1.6)	L
SS0195C6	.0195 Respond	1.258 \pm 0.017 (128.2 \pm 1.8)	M
SS0195C5	.0195 Unitek Twist	1.250 \pm 0.016 (127.4 \pm 1.6)	M
SS015T3	.015 Wildcat	0.927 \pm 0.008 (94.5 \pm 0.8)	N
SS0175C5	.0175 Unitek Twist	0.727 \pm 0.010 (74.1 \pm 1.0)	O
SS0175C6	.0175 Respond	0.691 \pm 0.008 (70.5 \pm 0.8)	P
SS0155C5	.0155 Unitek Twist	0.559 \pm 0.004 (57.0 \pm 0.4)	Q
Mean of all wires @ 2.0 mm		1.687 \pm 0.688 (172.0 \pm 70.2)	

SD, standard deviation; SNK Student-Newman-Keuls test.

to grams-force is 101.9716.¹¹ Additionally, results of the SNK post hoc analysis assigned the wire designs into statistically different groupings. Letters that are different indicate statistical differences ($P \leq .05$), and identical letters indicate no statistically significant dif-

ferences within its designated group. The force values in this article are presented in newtons and can be converted to centinewtons as stipulated by the revised specification⁹ in section 5.3.2.1 by dividing by 100. However, because section 6.2.4.6 (sampling and testing

Table IV. Ranking of wires by deactivation force at 1-mm deflection

Wire	Size (in) and trade name	Mean ± SD N (gmf)	SNK
SS0215T3	.0215 Tripleflex	1.316 ± 0.072 (134.2 ± 7.4)	A
SS0195T3	.0195 Wildcat	1.143 ± 0.045 (116.5 ± 4.6)	B
SS1825B9	.018 × .025 Force-9	1.036 ± 0.055 (105.6 ± 5.6)	C
SS1925B9	.019 × .025 Force-9	0.948 ± 0.055 (96.7 ± 5.6)	D
SS1725B8	.017 × .025 D-Rect	0.819 ± 0.042 (83.6 ± 4.3)	E
SS1622B8	.016 × .022 D-Rect	0.810 ± 0.030 (82.6 ± 3.0)	E
SS1825B8	.018 × .025 D-Rect	0.785 ± 0.040 (80.1 ± 4.1)	E
SS0215C5	.0215 Unitek Twist	0.733 ± 0.035 (74.7 ± 3.5)	F
SS1622B9	.016 × .022 Force-9	0.729 ± 0.026 (74.3 ± 2.7)	F
SS0215C6	.0215 Respond	0.705 ± 0.038 (71.9 ± 3.9)	F
SS0175T3	.0175 Wildcat	0.681 ± 0.024 (69.4 ± 2.5)	F
SS1925B8	.019 × .025 D-Rect	0.678 ± 0.040 (69.2 ± 4.1)	F
SS0195C5	.0195 Unitek Twist	0.677 ± 0.025 (69.0 ± 2.5)	F
SS0195C6	.0195 Respond	0.670 ± 0.021 (68.3 ± 2.2)	F
SS2125B8	.021 × .025 D-Rect	0.575 ± 0.059 (58.6 ± 6.0)	G
SS1725B9	.017 × .025 Force-9	0.571 ± 0.040 (58.2 ± 4.1)	G
SS015T3	.015 Wildcat	0.528 ± 0.018 (53.9 ± 1.8)	G
SS0175C5	.0175 Unitek Twist	0.367 ± 0.014 (37.4 ± 1.4)	H
SS0175C6	.0175 Respond	0.317 ± 0.012 (32.3 ± 1.3)	I
SS0155C5	.0155 Unitek Twist	0.305 ± 0.010 (31.1 ± 1.0)	I
Mean of all wires @ 1.0 mm		0.720 ± 0.257 (73.4 ± 26.2)	

SD, standard deviation; SNK, Student-Newman-Keuls test.

Table V. Ranking of wires by deactivation force at 0.5-mm deflection

Wire	Size (in) and trade name	Mean ± SD N (gmf)	SNK
SS0195T3	.0195 Wildcat	0.419 ± 0.045 (42.7 ± 4.6)	A
SS1622B9	.016 × .022 Force-9	0.309 ± 0.027 (31.5 ± 2.8)	B
SS1622B8	.016 × .022 D-Rect	0.305 ± 0.033 (31.1 ± 3.3)	B
SS0195C6	.0195 Respond	0.290 ± 0.025 (29.6 ± 2.6)	B/C
SS0195C5	.0195 Unitek Twist	0.272 ± 0.027 (27.8 ± 2.7)	B/C
SS0175T3	.0175 Wildcat	0.249 ± 0.020 (25.4 ± 2.8)	C
SS015T3	.015 Wildcat	0.245 ± 0.028 (24.9 ± 2.0)	C
SS0215C5	.0215 Unitek Twist	0.174 ± 0.036 (17.7 ± 3.7)	D
SS1825B9	.018 × .025 Force-9	0.171 ± 0.052 (17.4 ± 5.3)	D
SS1825B8	.018 × .025 D-Rect	0.133 ± 0.038 (13.6 ± 3.9)	D/E
SS0155C5	.0155 Unitek Twist	0.132 ± 0.011 (13.5 ± 1.2)	D/E
SS0175C5	.0175 Unitek Twist	0.129 ± 0.016 (13.2 ± 1.6)	D/E
SS1725B8	.017 × .025 D-Rect	0.128 ± 0.038 (13.0 ± 3.9)	D/E
SS0215T3	.0215 Tripleflex	0.118 ± 0.062 (12.0 ± 6.4)	D/E
SS1925B9	.019 × .025 Force-9	0.117 ± 0.049 (11.9 ± 5.0)	D/E
SS0175C6	.0175 Respond	0.081 ± 0.015 (8.2 ± 1.5)	E/F
SS0215C6	.0215 Respond	0.078 ± 0.027 (8.0 ± 2.8)	E/F
SS1925B8	.019 × .025 D-Rect	0.056 ± 0.024 (5.7 ± 2.5)	F/G
SS1725B9	.017 × .025 Force-9	0.017 ± 0.009 (1.7 ± 0.9)	G/H
SS2125B8	.021 × .025 D-Rect	-0-	H
Mean of all wires @ 0.5 mm		0.171 ± 0.110 (17.4 ± 11.2)	

SD, standard deviation; SNK, Student-Newman-Keuls test.

methods) specifies that the force data are to be measured in grams-force, both newton and grams-force units are presented.

At 3.0-mm deflection (Table II), most of the wire designs were distinctly different from one another ($P \leq$

.05), as indicated by the SNK post hoc comparison test, with the exception of the wire designs assigned to groups F, G, and L. The range of force delivery was 3.719 N (379.2 gmf) (0.12 to 4.431 N [72.6 to 451.8 gmf]). At 2.0-mm deflection (Table III), distinctly

Table VI. Ranking of wires by permanent deformation values

Wire	Size (in) and trade name	Mean \pm SD (mm)	SNK
SS2125B8	.021 \times .025 D-Rect	0.66 \pm 0.04	A
SS1725B9	.017 \times .025 Force-9	0.54 \pm 0.02	B
SS1925B8	.019 \times .025 D-Rect	0.44 \pm 0.03	C
SS0215T3	.0215 Tripleflex	0.43 \pm 0.02	C/D
SS1925B9	.019 \times .025 Force-9	0.43 \pm 0.02	C/D
SS1825B9	.018 \times .025 Force-9	0.39 \pm 0.02	C/D/E
SS1725B8	.017 \times .025 D-Rect	0.39 \pm 0.03	C/D/E
SS1825B8	.018 \times .025 D-Rect	0.38 \pm 0.02	C/D/E
SS0175C6	.0175 Respond	0.37 \pm 0.05	C/D/E/F
SS0215C6	.0215 Respond	0.36 \pm 0.06	C/D/E/F
SS0215C5	.0215 Unitek Twist	0.35 \pm 0.03	E/F
SS0175C5	.0175 Unitek Twist	0.31 \pm 0.03	F
SS0175T3	.0175 Wildcat	0.25 \pm 0.03	G
SS1622B8	.016 \times .022 D-Rect	0.24 \pm 0.02	G/H
SS0155C5	.0155 Unitek Twist	0.23 \pm 0.04	G/H
SS0195T3	.0195 Wildcat	0.23 \pm 0.02	G/H
SS0195C5	.0195 Unitek Twist	0.22 \pm 0.02	G/H
SS1622B9	.016 \times .022 Force-9	0.20 \pm 0.02	G/H
SS0195C6	.0195 Respond	0.18 \pm 0.02	G/H
SS015T3	.015 Wildcat	0.17 \pm 0.02	H
Mean of all wires		0.34 \pm 0.13	

SD, standard deviation; SNK, Student-Newman-Keuls test.

different force deliveries were still observed, with the exception of the wire designs assigned to groups H, I, J, and M. The range of force delivery was smaller, 2.584 N (263.5 gmf) (0.559 to 3.143 N (57.0 to 320.5 gmf)). At 1.0-mm deflection (Table IV), considerable similarity in the force delivery of the wires was observed; however, distinct differences were still maintained. The range of force delivery declined further to 1.011 N (103.1 gmf) (0.305 to 1.316 N [31.1 to 134.2 gmf]). At the 0.5-mm deflection (Table V), similarity of force delivery was the predominant observation, and force delivery was smaller yet, 0.419 N (42.7 gmf) (0.00 to 0.419 N [0 to 42.7 gmf]). The mean force values for all wire designs at 3, 2, 1, and 0.5 mm were 2.319 N (236.5 gmf), 1.687 N (172.0 gmf), 0.720 N (73.4 gmf), and 0.171 N (17.4 gmf), respectively. The wires tested exhibited a significant degree of elasticity, as shown by the low values for permanent deformation in Table VI, and ranged from 0.17 to 0.66 mm, with a mean value of 0.34 mm for all wire designs.

DISCUSSION

The data obtained in this study provide force values for the deflections required by the revised ANSI/ADA Specification No. 32. Figure 3 is a box plot illustrating the range of force values and means for the 20 multistranded stainless steel wire designs tested.

The methodology used in this study involved no restraint of the wire specimens at the supports by

clamping or using brackets of various designs. The high degree of elasticity, however, yielded deactivation force values comparable to titanium-containing wires.^{12,13} Complexities produced by clinically simulated testing apparatuses might not provide any more clinically relevant data than does the simple flexural test used in this study. The relatively compact grouping of the force ranges at each deflection suggests that the impact of the design variables of weave, cross-section, and number of strands, although difficult to theoretically quantify, might not result in as wide a range of force values on unloading as might be expected. Additionally, the use of restraining mechanisms and brackets at the supports for flexural tests introduces the effects of frictional forces and mechanical binding; these might increase the scatter of values obtained during testing. This study allows for direct comparison of wires of significantly different fabrication design. For these multistranded wires, the design variables are confounding factors when one attempts to identify trends (eg, the effect on force level of varying cross-sectional size or number of strands). The determination of trends would require the control of all design factors except that under measurement (eg, number of strands). Then, by varying this independent variable, the effect, if any, on the required parameters as stipulated in the specification could be observed. Additional complexity is added by the possible effects of interstrand friction, compaction force dur-

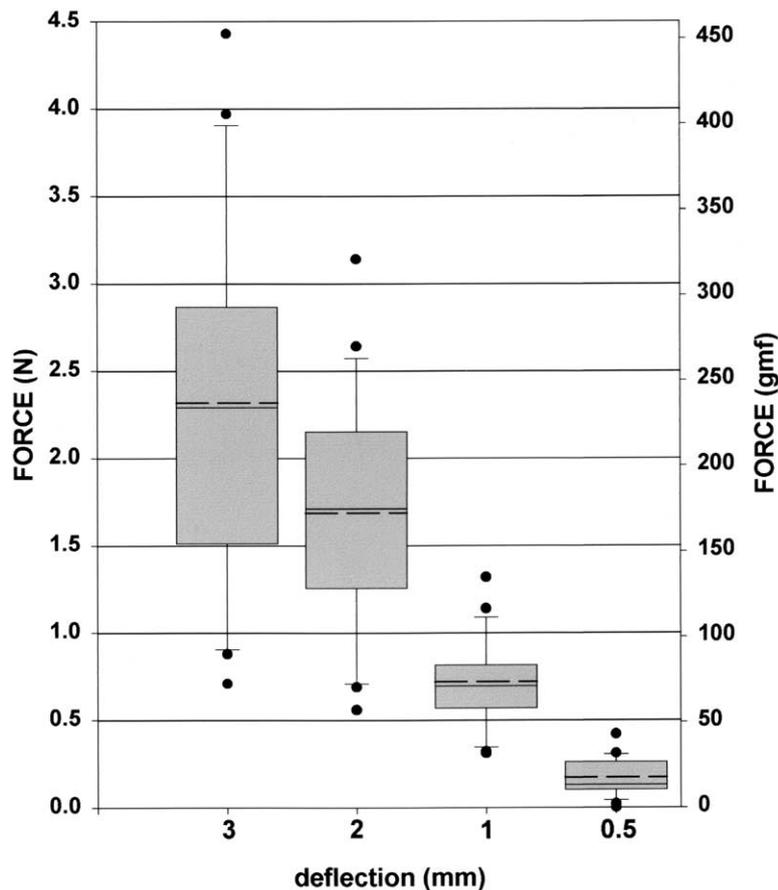


Fig 3. Force levels at 3-, 2-, 1-, and 0.5-mm deflections. Bottom of each box indicates 25th percentile. *Dashed line* in each box is mean, and *solid line* is median of values. Top of each box indicates 75th percentile. *Error bars* above and below box indicate 90th and 10th percentiles, respectively. *Solid dots* representing outliers are also shown.

ing fabrication of a particular cross-section, and the manufacturers' proprietary heat treatments.^{14,15} Usually, there are not enough cross-sections available within the same weave design and number of strands to allow studying the effect of cross-section alone. The same holds for studies of the effect of weave and number of strands.

Previous investigations have suggested that multi-stranded stainless steel wires are an economical alternative to nickel-titanium alloy wires.^{3,14} For example, the elastic characteristics of .0175-in triple-stranded wires and .016-in nickel-titanium wires were found to be comparable. Although multistranded wires might be a viable alternative to nickel-titanium wires, on deactivation, they do not display the consistently low and moderately decreasing forces at the different deflections, as do the nickel-titanium wires. Therefore, the clinician must have a knowledge of the behavior of multistranded wires when using them as substitutes for titanium-containing wires.

Comparison of data for solid wires with those obtained in this study would be instructive in supporting substitution of multistranded wires for solid wires when increased working ranges or lower force values are desirable.

An extension of this study would involve looking at the effect of support restraint by brackets on the level of force generated on deactivation. A study on selected nickel-titanium wires has been published and indicates that varying force levels are the result of experimental model design.¹³ Varying span lengths have been used in published studies, and this variable should be uniform to accurately make comparisons.^{16,17}

CONCLUSIONS

The analyses of the data obtained in this study support the following conclusions:

1. Multistranded wires of significantly different cross-section, weave, and strand number fell within relatively narrow ranges of force magnitude at 1- and 0.5-mm deflections. Wider ranges were observed at 3- and 2-mm deflections, requiring the clinician to critically select multistranded wires to obtain the desired force levels.
2. The braided weave designs, with a few exceptions, provided the higher levels of force delivery at 3-, 2-, and 1-mm deflections, whereas the coaxial weaves produced lower force levels at those deflections. No trend with respect to weave was observed at the 0.5-mm deflection.
3. For type 2 nonlinear elastic wires, the specification guidelines for testing provided a means for obtaining unloading force delivery data for the deflections required. The testing also showed that multistranded wires of significantly different designs exhibit similar force levels, particularly at small deflections.
4. All wires exhibited some permanent deformation, but none averaged greater than 0.66 mm, indicating significant elasticity in multistranded wires.

REFERENCES

1. Craig RG, Powers JM. Restorative dental materials. 11th ed. St. Louis: Mosby; 2002. p. 81.
2. Nikolai RJ. Flexural activation and de-activation responses of orthodontic wires in single-tooth, occlusogingival corrections. Dent Mat 1989;5:339-45.
3. Kusy RP, Dilley GJ. Elastic property ratios of a triple-stranded stainless steel archwire. Am J Orthod 1984;86:177-88.
4. Jones ML, Staniford H, Chan C. Comparison of superelastic NiTi and multistranded stainless steel wires in initial alignment. J Clin Orthod 1990;24:611-3.
5. New American Dental Association Specification No. 32 for orthodontic wires not containing precious metals. Council on Dental Materials and Devices. J Am Dent Assoc 1977;95:1169-71.
6. Schaus JG, Nikolai RJ. Localized, transverse, flexural stiffnesses of continuous arch wires. Am J Orthod 1986;89:407-14.
7. Ingram SB, Gipe DP, Smith RJ. Comparative range of orthodontic wires. Am J Orthod Dentofacial Orthop 1986;90:296-307.
8. Nikolai RJ, Anderson WT, Messersmith ML. Structural responses of orthodontic wires in flexure from a proposed alternative to the existing specification test. Am J Orthod Dentofacial Orthop 1988;93:496-504.
9. Revised American National Standards Institute/American Dental Association Specification No. 32 for orthodontic wires. Council on Scientific Affairs. Copy can be obtained from the American Dental Association.
10. Brantley WA, Eliades T. Orthodontic materials—scientific and clinical aspects. New York: Thieme; 2001. p. 89.
11. Tuma JJ. Handbook of physical calculations. New York: McGraw-Hill; 1976. p. 330.
12. Oltjen JM, Duncanson MG Jr, Ghosh J, Nanda RS, Currier GF. Stiffness-deflection behavior of selected orthodontic wires. Angle Orthod 1997;67:209-18.
13. Wilkinson PD, Dysart PS, Hood JAA, Herbison GP. Load-deflection characteristics of superelastic nickel-titanium orthodontic wires. Am J Orthod Dentofacial Orthop 2002;121:483-95.
14. Kusy RP, Stevens LE. Triple-stranded stainless steel wires—evaluation of mechanical properties and comparison with titanium alloy alternatives. Angle Orthod 1987;57:18-32.
15. Khier SE, Brantley WA, Fournelle RA. Structure and mechanical properties of as-received and heat-treated stainless steel orthodontic wires. Am J Orthod Dentofacial Orthop 1988;93:206-12.
16. Brantley WA, Augat WS, Myers CL, Winders RV. Bending deformation studies of orthodontic wires. J Dent Res 1978;57:609-15.
17. Brantley WA, Myers CL. Measurement of bending deformation for smaller diameter orthodontic wires. J Dent Res 1979;58:1696-700.

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