Original Article

Contemporary esthetic nickel-titanium wires: *Do they deliver the same forces?*

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ABSTRACT

Objective: To test for differences in loading and unloading forces delivered by six coated nickel-titanium wires and their noncoated equivalents.

Materials and Methods: From six commercial companies, 0.016-inch diameter round and 0.016 × 0.022-inch rectangular cross-section nickel-titanium wires were procured "as is": Rocky Mountain Orthodontics (Denver, Colo), TP Orthodontics (La Porte, Ind), American Orthodontics (AO; Sheboygan, Wis), G&H (Franklin, Ind), Opal Orthodontics (South Jordan, Utah), and Forestadent USA (St Louis, Mo) (round only). The wires were evaluated using a three-point bending test based on the method in ISO Standard 15841.

Results: No statistically significant differences ($P > .05$) in force values were found between coated and noncoated wires, listed by deflection in three-point bending, for these specific groups: 1 mm, TP round; 2 mm, TP round and G&H rectangular; 3 mm, G&H round and G&H rectangular; 2.5 mm,TP round and G&H rectangular; 1.5 mm, TP round, G&H round, G&H rectangular, and AO rectangular; and 0.5 mm, AO rectangular and G&H round.

Conclusion: Some manufacturers market esthetic wires delivering forces similar to the equivalent noncoated wires, when tested according to a standard three-point bend method. (*Angle Orthod.* 2015;85:95–101.)

KEY WORDS: Nickel-titanium archwires; Orthodontics

INTRODUCTION

The demand for more esthetic orthodontic treatment modalities is growing. This trend is understandable since patients hope for improved appearance and the number of adult patients is increasing. For instance, in a recent study, the combination of esthetic archwires and sapphire brackets ranked second in patient preferences, only behind clear aligners.[1] Beginning in the 1970s with plastic brackets constructed from acrylic and later polycarbonate, there have been many iterations toward achieving a more esthetic or tooth colored bracket.[2] Yet, not as much interest has been focused on the esthetics of the other component of the fixed orthodontic appliance, the wire. As mentioned by Kaphoor and Sundareswaran,[3] some previous studies examined coated wires with respect to coating durability and friction properties. However, these studies did not evaluate the difference in force delivery values between these coated and noncoated wires using a standardized testing procedure.

Two types of esthetic wires exist, namely, traditional nickel-titanium wires with a chemical coating and a fiber-reinforced composite wire. The latter, although it offers great promise for the future, is not available commercially as of this writing. The materials traditionally used to coat wires are synthetic fluoropolymers such as polytetrafluoroethylene (PTFE), epoxy PTFE resins, or a combination of the two.[4] Historically, the orthodontic literature has shown that these coated

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wires may deliver lower loads than their noncoated equivalents.[5] An explanation is that the nominal active dimension of the wire is changed by the thickness of the coating, so the underlying wire is smaller in cross section. In 2011, Adini et al.[6] described a new technology that uses inorganic fullerene nanoparticles to coat the wire without increasing its diameter significantly. However, this nanoparticle covering is not yet available for commercial manufacturing. Recent studies have shown that coated wires may now be able to generate forces similar to the non-coated wire, particularly when only the labial surface of the wire is coated.[3]

The null hypothesis in this study is that for an individual manufacturer, there will be no difference in load response between coated and noncoated nickel-titanium wires of the same size when subjected to the same deflections using a standard three-point bend test method.

MATERIALS AND METHODS

Both 0.016-inch diameter round and 0.016 × 0.022-inch rectangular cross-section wires were selected for use. These dimensions were selected because they are commonly used in clinical orthodontic treatment and are well characterized in the orthodontic literature. These two wire sizes approximate the lower and upper limits of the range of wire sizes used in the initial leveling and alignment phase of orthodontic treatment, with edgewise appliances having a bracket slot size of 0.022 × 0.028. All wire sizes were verified from the manufacturer and measured with a digital micrometer (#O4OO-EEP, Electric Digital Caliper Orthodontic Tip; Orthopli, Philadelphia, Penn) with a resolution of 0.001 inches. The wires were donated directly from the manufacturers and all from the same lots. All wires received and tested were unused and in the original packaging at time of receipt.

Nickel-titanium maxillary preformed segments of 0.016-inch and 0.016 × 0.022-inch cross-section wires were procured from six commercial companies: Rocky Mountain Orthodontics (RMO; Denver, Colo), TP Orthodontics (La Porte, Ind), American Orthodontics (AO; Sheboygan, Wis), G&H (Franklin, Ind), Opal Orthodontics (South Jordan, Utah), and Forestadent USA (St Louis, Mo). Each company had both a rectangular and round group (except Forestadent USA, which had only round), yielding 11 total groups. Ten wire specimens of 0.016-inch diameter round and 0.016 × 0.022-inch cross-section rectangular were prepared using the following protocol: as specified in the ISO 15841 standard, a 30-mm section was cut from the straightest portion of the distal ends of a preformed wire using a common cutter, and the remaining portion was discarded. The cross section of each 30-mm section was then verified using a micrometer, marked with a permanent marker at 15 mm, and tested based on the three-point bend method specified in the standard ISO 15841 "Dentistry Wires for Use in Orthodontics,"[7] except that the temperature was 23°C. Briefly, the key test parameters of ISO 15841 are the following: the cross-head speed was 7.5 mm/min, the span between the supports was 10 mm, the radii of fulcrum and indenter were 0.1 mm, and the wires were centrally deflected 3.1 mm. The wires from each company were sorted and tested by the principal investigator. Because of the distinct nature of each wire, blinding was not necessary. Rectangular wires were tested in the direction of the height, as per the standard. The coated wires were manufactured with a variety of different materials and thicknesses: Forestadent and Opal wires are manufactured with a 0.002-inch epoxy coating; G&H uses a proprietary polymer coating listed as <0.002; AO uses Everwhite, a proprietary polymer coating, which is 0.001 inches thick; TP uses a labial-only Teflon coating, which is 0.005 inches; and RMO uses a 0.002-inch average thickness Teflon.

An Instron universal testing machine (model 5582, Norwood, Mass) with MTS TestWorks 4 software (version 4.12 D, Eden Prairie, Minn) equipped with a 1-kN capacity load cell was used for the experiments. The experiments were performed at the Research and Laboratories of the American Dental Association (Chicago, Ill), where the equipment was properly calibrated prior to testing. Representative load-deflection output from the test apparatus is shown in Figure 1. A sample of 10 wires in each study group was used in accordance with usual practice in the orthodontic literature. Statistical analysis was done using SPSS version 19.0 (Chicago, Ill). Analysis of variance was performed with Sheffé post hoc for the mean comparison among the measurements of each loading and unloading deflection for coated and noncoated wires. Student's *t*-tests were performed for the mean comparisons between noncoated and coated groups for each deflection.

RESULTS

Table 1 shows, for each manufacturer, the descriptive statistics ($n = 10$) and the test results for the comparison of wires found to be approximately the same, that is, displaying no statistical difference ($P > 0.5$) as related to mean force (N) values at different deflections (mm) of each group (manufacturer). Similar force values between coated and noncoated wires are indicated. Additional data from experiments showing differences between coated and noncoated wires are available.[8]

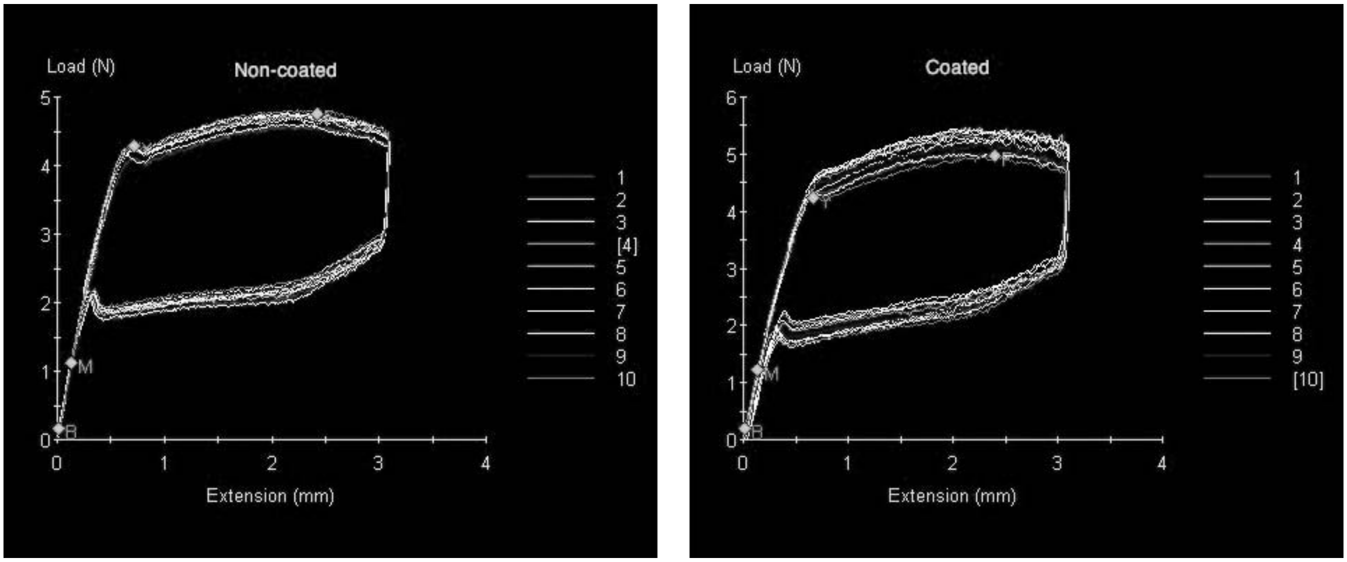

Figure 1. Representative output from the experimental apparatus. Mean force levels in group AO rectangular coated and noncoated wires. (Left) Load deflection curves for group AO rectangular coated wires. (Right) Load deflection curves for group AO rectangular noncoated wires.

Four of the eleven groups exhibited at lease some load responses that were significantly different ($P > 0.05$) at the same deflection for coated and noncoated wires. These groups were TP Orthodontics round, G&H round and rectangular, and AO rectangular. At 1 mm loading deflection, only TP round wires exhibited no difference between the coated and noncoated wires. At 2 mm, TP round and G&H rectangular wires exhibited no difference in force values between the respective coated and noncoated wires upon loading.

Table 1. Comparisons of Mean Force (N) Between Coated and Noncoated Nickel-Titanium Wires at Different Deflections (mm) by Manufacturers

Manufacturer	Variables	Deflections, mm	n[a]	Coated Mean ± SD,[a] N	Noncoated Mean ± SD,[a] N	*P* Value*
TP round	Loading	1	10	2.33 ± 0.11	2.33 ± 0.03	.910
		2	10	2.55 ± 0.11	2.50 ± 0.03	.190
		3	10	2.41 ± 0.13	2.30 ± 0.05	.032
	Unloading	2.5	10	1.49 ± 0.09	1.54 ± 0.05	.115
		1.5	10	1.27 ± 0.10	1.29 ± 0.04	.647
		0.5	10	0.92 ± 0.09	1.12 ± 0.02	<.001
G&H round	Loading	1	10	2.08 ± 0.05	1.99 ± 0.04	<.001
		2	10	2.35 ± 0.05	2.22 ± 0.03	<.001
		3	10	2.27 ± 0.20	2.18 ± 0.04	.193
	Unloading	2.5	10	1.28 ± 0.05	1.20 ± 0.05	.002
		1.5	10	1.02 ± 0.20	0.98 ± 0.04	.077
		0.5	10	0.87 ± 0.03	0.90 ± 0.07	.176
G&H rectangular	Loading	1	10	4.11 ± 0.06	4.26 ± 0.06	<.001
		2	10	4.52 ± 0.08	4.53 ± 0.06	.581
		3	10	4.34 ± 0.06	4.14 ± 0.49	.217
	Unloading	2.5	10	2.17 ± 0.06	2.23 ± 0.08	.071
		1.5	10	1.67 ± 0.04	1.71 ± 0.07	.147
		0.5	10	1.44 ± 0.05	1.67 ± 0.07	<.001
AO rectangular	Loading	1	10	4.67 ± 0.17	4.30 ± 0.07	<.001
		2	10	5.19 ± 0.20	4.67 ± 0.07	<.001
		3	10	4.98 ± 0.21	4.47 ± 0.08	<.001
	Unloading	2.5	10	2.60 ± 0.11	2.38 ± 0.07	<.001
		1.5	10	2.16 ± 0.13	2.08 ± 0.07	.105
		0.5	10	1.83 ± 0.15	1.87 ± 0.06	.405

[a] SD indicates standard deviation; n, number of wires used for analysis; TP, TP Orthodontics; AO, American Orthodontics.

* Statistically significant at $P < .05$.

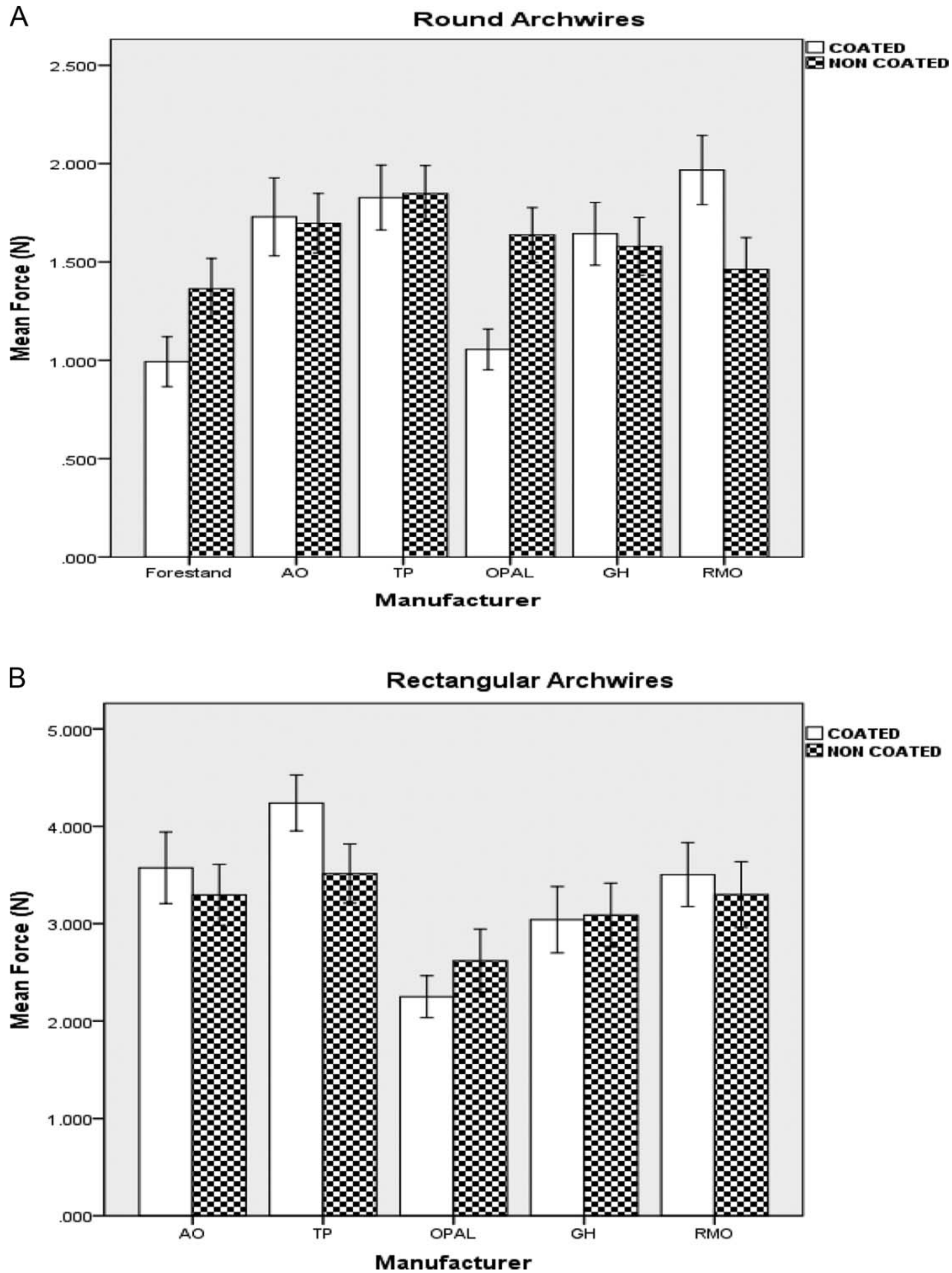

Figure 2. Mean differences between coated and noncoated nickel-titanium wires (error bars: 95% confidence interval). (A) Round archwires. (B) Rectangular archwires.

At 3 mm, loading deflection showed similar force values with G&H round and rectangular. At 2.5 mm unloading, only TP round and G&H rectangular exhibited no difference in the force values. At 1.5 mm unloading, there was no difference in mean force values between the groups TP round, AO rectangular, G&H round, and G&H rectangular. At 0.5 mm unloading, G&H round and AO rectangular proved to be similar. Figure 2A,B summarizes the differences between coated and noncoated wires at all deflections.

DISCUSSION

The in vivo functionality of coated archwires with respect to friction and durability of the coating is well documented in the literature.[8] Most studies were performed with stainless-steel wires and did not address the basic premise of whether the mechanical force values of the wire are changed by the coating. There are very few publications in the orthodontic literature that address mechanical properties of coated vs noncoated super elastic wires.[3]

Measurement of the force (N) at loading and unloading extensions was able to provide insight regarding the tooth-moving properties of various wires. Four of the 11 groups tested (TP round, AO rectangular, G&H round, G&H rectangular) exhibited at least some load responses that were not significantly different ($P > .05$) at the same deflection for coated and noncoated wires. For an individual manufacturer, if the coated and noncoated wires are of the same size, the cross-sectional area of the wire beneath the coated sample must be smaller. However, in a 2013 study that examined the cross-section dimensions of esthetic orthodontic coated archwires from four different manufacturers, the authors found that for one manufacturer (TP Orthodontics), there was no significant difference between the inner alloy core dimensions of the coated wires (Aesthetic Shiny Bright) and the noncoated wires (Shiny Bright).[9] In the Materials and Methods section of this article, it was noted that the nominal dimensions of the wires were measured using a micrometer with a resolution of 0.001 inches. However, to further investigate the dimensions of the coated and noncoated wires similar to the aforementioned 2013 study, a Nikon Profile Projector (Nippon Kogaku, Tokyo, Japan) with a resolution of 0.00001 inches was used to examine the wires at 100× magnification. For each manufacturer, a random sampling of the wires was measured, and for the coated wires, the coating was first dissolved using methyl ethyl ketone. The profiles of the wires were measured along their respective lengths, and the averages were recorded. For the round wires, the TP and GH wires had similar diameters for the coated and noncoated wires: TP coated, 0.01578 inches; TP noncoated, 0.01618 inches; GH coated, 0.01557 inches; and GH noncoated, 0.01567 inches. Likewise, for the rectangular wires, the GH and AO wires had similar dimensions for the coated and noncoated wires: GH coated, 0.01552 × 0.02148 inches; GH noncoated, 0.01547 × 0.02127 inches; AO coated, 0.01562 × 0.02168 inches; and AO noncoated, 0.01513 × 0.02117 inches. As noted above, it is these four groups that exhibited at least some load responses that were not significantly different at the same deflection for coated and noncoated wires. Therefore, from closer examination of the wires with the profile projector, it can be seen that the reason for these groups' exhibiting some load responses that were similar for the coated and noncoated wires is that, for each of these manufacturers, the respective coated and noncoated wires (with the coating dissolved) have approximately the same dimensions.

One can devise a tier system to order the method of manufacturing based on statistical differences between coated and noncoated wires.[8] In tier 1, the 0.0050-inch Teflon coating labial-only TP round wires, the 0.001-inch Everwhite coating (harder than Teflon) AO wires, and the <0.002-inch proprietary polymer coating G&H wires performed almost identically to their respective noncoated versions in terms of force values. In tier 2, the 0.001- to 0.003-inch Teflon coating labial-only RMO wires and the 0.005-inch Teflon coating labial-only TP rectangular wires performed slightly better than the noncoated wires, with the coated wires exhibiting higher load response values. Using the profile projector, as described above, the dimensions of the coated wires (with the coating removed) and the noncoated wires were measured: RMO round coated, 0.01608 inches (0.00013 inches); RMO round noncoated, 0.01613 inches (0.00013 inches); RMO rectangular coated, 0.01583 × 0.02160 inches (0.00016 × 0.00028 inches); RMO rectangular noncoated, 0.01590 × 0.02135 inches (0.00018 × 0.00018 inches); TP rectangular coated, 0.01560 × 0.02145 inches (0.00010 × 0.00026 inches); and TP rectangular noncoated, 0.01587 × 0.02042 inches (0.00013 × 0.00045 inches). Standard deviations are provided in parentheses to show that although the average dimensions are similar for the wires of an individual manufacturer, it is possible that there may be enough deviation in the dimensions to cause slight differences in the load responses between the respective coated and noncoated wires. In tier 3, the 0.002-inch epoxy-coated Forestadent and Opal wires showed the greatest difference in force values, with the coated wires exhibiting lower load response values. Again, using the profile projector, as described above, the dimensions of the coated wires and the noncoated wires were measured, and the coated wires (with the coating removed) had smaller dimensions than the noncoated wires: Forestadent round coated, 0.01365 inches; Forestadent round noncoated, 0.01578 inches; Opal round coated, 0.01368 inches; Opal round noncoated, 0.01578 inches; Opal rectangular coated, 0.01372 × 0.01902 inches; and Opal rectangular noncoated, 0.01543 × 0.02135 inches.

The use of ISO Standard 15841 as a guide for this study is one of its strengths. Variables such as span length, size of the loading instrument, loading speed, method of ligation, and direction of testing can yield varying results from the same piece of wire tested in different manners. In the literature, previous three-point bend testing used an arbitrary span length (usually 14 mm, which is the span from a central incisor to canine), and the method of ligation varied from none to ligation with conventional or even self-ligating brackets.[10,11] These inconsistencies make comparisons of the results between these studies problematic. The use of an agreed-upon standard allows for replication and comparison of studies and can provide a more efficient way to test new wires developed by manufacturers. In ISO Standard 15841, all of these key variables are set.

A weakness of this study is that the tests were performed at 23°C instead of the 36°C specified in ISO 15841. It is known that superelastic deformation behavior is strongly dependent on deformation temperature, and it has been shown that the stresses for superelastic deformation and superelastic reverse deformation increase with increasing temperature.[12] Therefore, the load response values obtained in this study may be higher at 36°C. It also worth noting that ISO 15841 requires that the bending forces during unloading be reported. In this study, we reported bending forces for both loading and unloading. It has been suggested that for three-point bend tests, the loading section of the curve represents the force required to engage the wire in the bracket, while the unloading section of the curve represents the forces applied to the teeth during the leveling and aligning phase of treatment.[13] Therefore, it could be argued that the data provided by the unloading curve may be the more clinically relevant information.

This study directly relates to the practice of evidence-based dentistry. It provides a specific guide for round and rectangular coated wires that perform similar to their uncoated counterparts with respect to load response, which can help the clinician with selection of these coated archwires. For example, if the clinician uses a 0.022-inch slot appliance and desires the force levels of a conventional 0.016-inch super elastic wire, there are three choices: (1) select a wire manufactured with a labial-only coating and the dimensions of 0.016 inches, (2) select a wire with an 0.002-inch epoxy coating and an overall size of 0.018 inches, or (3) select one of the wires listed with a low overall mean difference between coated and non-coated wires. There are myriad iterations of these, and it is not the scope of this article to discuss each one in detail or to dictate treatment mechanics; however, the data generated by this study can be used to guide clinical decision making. This study was limited by the lack of information available from manufacturers regarding their manufacturing process of the nickel-titanium wires. A number of factors may influence the wire properties, including but not limited to austenite finish temperatures, temperatures used during coating application, actual thickness of coatings, and exact composition of coating. Manufacturers should supply buyers with testing data obtained according to recognized standards so that buyers can make informed decisions when choosing between different wires.

CONCLUSIONS

- It has been shown that for some manufacturers, there is no significant difference in load response between coated and noncoated nickel-titanium wires of the same size when subjected to the same deflections using a standard three-point bend test method.
- Specifically, esthetic wires exhibiting similar load responses to their noncoated counterparts are these:
  - 1-mm deflection: 0.016-inch TP round
  - 2-mm deflection: 0.016-inch TP round, 0.016 × 0.02-inch G&H rectangular
  - 3-mm deflection: 0.016-inch G&H round, 0.016 × 0.022-inch G&H rectangular
  - 2.5-mm deflection: 0.016-inch TP round, 0.016 × 0.022-inch G&H rectangular
  - 1.5-mm deflection: 0.016-inch TP round, 0.016-inch G&H round, 0.016 × 0.022-inch G&H rectangular, 0.016 × 0.022-inch AO rectangular
  - 0.5-mm deflection: 0.016-inch G&H round, 0.016 × 0.022-inch AO rectangular

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