The effect of long-term deflection on permanent deformation of Nickel-Titanium archwires

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The orthodontic practitioner has access to a variety of archwires to begin treatment and initiate tooth movement. The development of beta-titanium (TMA), nickel-titanium (Nitinol), superelastic nickel-titanium and multistrand stainless steel wires has made selecting the best archwire for a particular application complex. Presently, a plethora of archwires of different sizes, shapes, alloys and manufacturer are available.[1-3]

Several laboratory studies have been conducted concerning working range or permanent deformation of archwires. Andreasen and Barret[4] deflected wires for one hour between malposed typodont teeth. Nitinol exhibited 5% to 55% greater working range than single and multistrand stainless steel wires, depending on deflection, interbracket distance and wire. Barrows,[5] similarly found that Nitinol exhibited a larger working range than stainless steel and multistrand stainless wires. Andreasen and Morrow[6] found no permanent deformation when Nitinol was deflected for less than 1 hour.

Barrows[5] also found distortion increased 7% after 8 weeks when compared to the 1 hour interval. Lopez, Goldberg & Burstone[7] and Burstone, Qin & Morton[8] found Nitinol experiences time-dependent stress relaxation. Harris, Newman and Nicholson[9] studied mechanical properties of Nitinol after 1, 2 and 4 months of deformation and found the 0.2% yield strength decreased by 15%. Newer nickel-titanium wires, Chinese NiTi wire[8] and Japanese NiTi wire[10] exhibited less permanent deformation than did Nitinol.

Data comparing permanent deformation after long-term deflection of the multitude of brand name nickel-titanium wires is lacking. The purpose of this study is to compare long-term per-

Abstract

The clinician must now consider the alloy along with cross-sectional shape and size when selecting archwires. The purpose of this study is to quantify permanent deformation after long-term deflection of available nickel-titanium archwires. Nine nickel-titanium, one beta-titanium and one stainless steel archwires, .016 inch round, were deflected into orthodontic brackets of simulated archform. One lateral incisor was positioned to yield a deflection of 5 mm in a lingual direction. After wire deactivation, deformation was measured at 1, 14, and 28 days. Two-way ANOVA and Tukey's critical difference tests were used to determine statistical differences. The nickel-titanium wires exhibited better springback characteristics and less permanent deformation than the stainless steel and TMA wires. Several wires increased deformation as deflection time increased. No clinically significant difference was found between presently available nickel-titanium wires in terms of permanent deformation, long- or short-term.

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Key Words

Orthodontic wires • Nitinol • Spring back • Permanent deformation • Stress-relaxation

Table I
Wire name and Source

Align	A-Company, San Diego, CA 92138
Force 1	American Orthodontics, Sheboygan, WI 53028
Sentalloy Medium	GAC, Central Islip, NY 11722
Titanal	Lancer, Carlsbad, CA 92008
NiTi	Ormco, Glendora, CA 91740
Orthonol	Rocky Mountain, Denver, CO 80217
Reflex	TP Orthodontics, LaPorte, IN 46350
Nitinol	Unitek, Monrovia, CA 91017
Nitinol SE	Unitek, Monrovia, CA 91017
TMA	Ormco, Glendora, CA 91740
Permachrome Stainless Steel	Unitek, Monrovia CA 91017

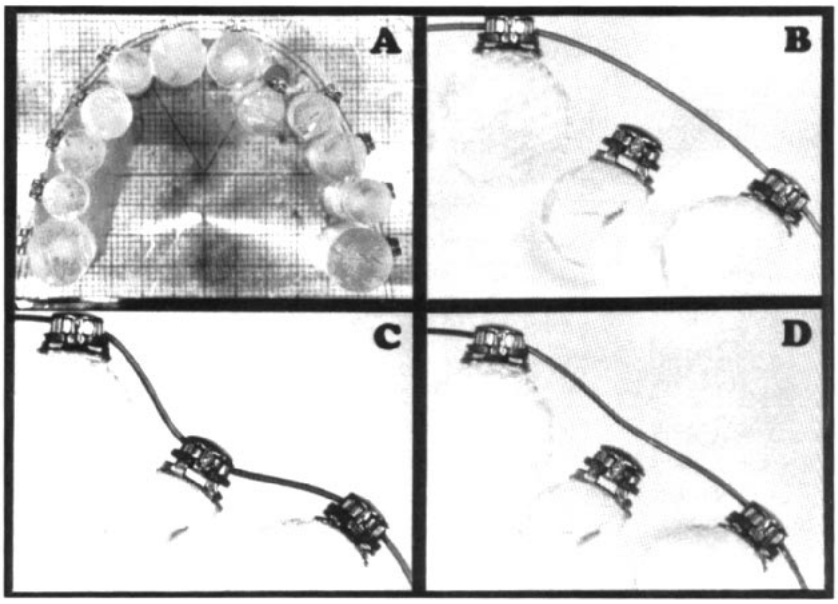

Figure 1
(A) Occlusal view of pentamorphic archform; (B) Wire in archform before activation; (C) Wire deflected into bracket slot; (D) Wire released from bracket slot.

manent deformation of different nickel-titanium wires in a clinical simulation.

Materials and methods

Nine 0.016 ″ diameter round wires, donated by the manufacturers (Table I), were tested as received using a preformed "ideal" archform similar to Schaus and Nikolai.[11] One beta-titanium wire and one stainless steel wire were included for comparison. Archforms vary in shape between companies. Such variation affects wire fit, stiffness and friction as the archwire slides through the slot during activation.[11] Conclusions drawn must be considered in regard to wire fit to the archform.

The chosen archform[11] was that of a 13-year-old female as detailed by Moyers.[12] The arch was constructed of plexiglass rods chosen to approximate the average mesiodistal dimensions of the maxillary dentition from 1st molar to 1st molar, as listed in Wheeler's text of Dental Anatomy,[13] Figure 1a.

Bonded to each dowel rod was a 0.018″ slot standard bracket which was self-ligating,* suppressing potential variability in otherwise hand-tied or ringed ligations. All brackets were positioned and aligned such that the mesiodistal slot axes were all contained in the same plane. To incorporate a realistic setting, archwire activation was represented by a 5 mm lingually malposed maxillary lateral incisor, Figure 1a. Interbracket distance was predetermined by the archform chosen and the brackets used, and were constant throughout all tests. The interbracket span between the maxillary central and canine was 19 mm. The effect of a long-term, 5 mm lingual deflection on permanent deformation in the sample wires was determined for time intervals of 1, 14, and 28 days.

Permanent deformation in the wire was measured to ± 0.04 mm in the following manner. The untested wire was placed into the simulated archform with all brackets engaged except the offset lateral incisor, Figure 1b. A microscope** was used to measure the closest approach of the lingual edge of the wire to the facial surface of the bracket to ± 0.04 mm. After the initial measurement, the archwire was deflected into the slot of the malposed tooth and held for its prescribed interval, Figure 1b. Because some wires are promoted as being thermally active, all specimens were stored in a 37°C water bath. At the end of the activation test period, the archwire was released from the bracket of the lateral incisor and remeasured, Figure

* Edgelock, Ormco, Glendora, CA 91740
** Unitron, Series N, Newton Heights, MA

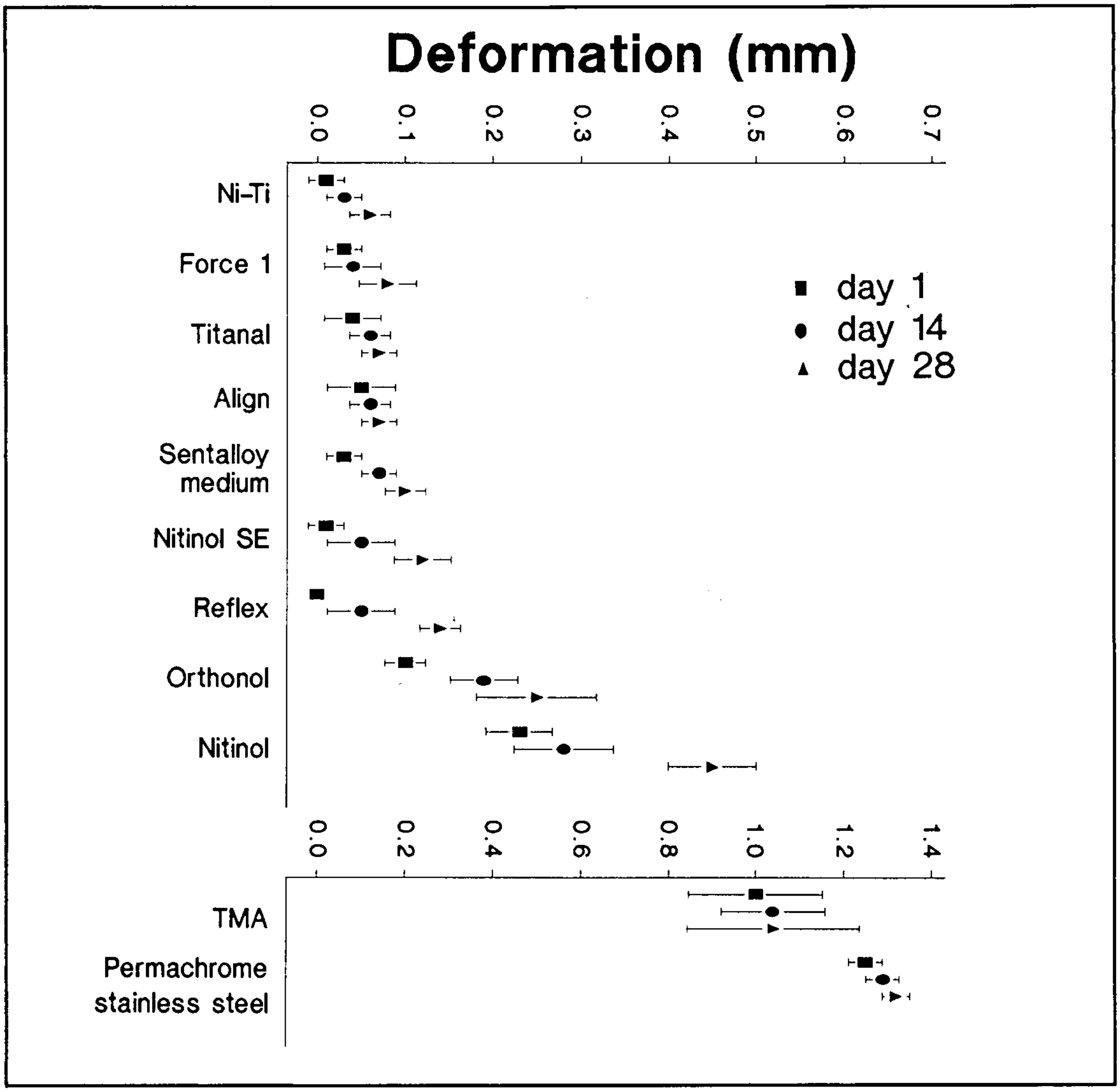

Figure 2
Average permanent deformation.

1d. Values of permanent deformation reported are the initial measurement of the wire prior to deflection into the bracket minus the second measurement after release. Four new and separate wires were tested for each time interval making each test independent of all others.

Often, after a wire was released and immediately measured, more springback occurred subsequent to this initial measurement. This "delayed rebound effect" ranged from 0.04 mm to 0.08 mm. Reported measurements were made 1 hour after the wire was released, when full springback had occurred.

Data for all measurements were statistically analyzed using random complete block design ANOVA to isolate the differences between comparable sample means. Differences in the amount of permanent deformation were analyzed using two-way ANOVA*** (wire type and time interval) and Tukey's critical difference test for unconfounded comparisons[14] at $p<0.05$.

*** ABSTAT 5.0, Anderson-Bell, Cannon City, CO

Results

Table II lists the means and standard deviations of permanent deformation at each time interval. Results of Table II are graphically presented in Figure 2. Values for permanent deformation are recorded in millimeters. The range of averages for the 1-day deflection interval was from 0.00 to 1.25 mm of deformation. The averages ranged from 0.03 to 1.29 mm after 14 days and 0.06 to 1.32 mm after 28 days. The table also shows significant statistical differences. Means of no statistical difference are denoted by the vertical lines next to the means.

The two-way ANOVA showed wire type and time interval factors to be significant. Though usually not statistically significant, each wire exhibited increased deformation with time. The 14-day interval showed an increase in deformation over the 1-day interval, and the 28-day deflection interval showed an increase in deformation over the 14-day interval. Nitinol, Orthonol, Sentalloy, Force 1, Nitinol SE, Reflex, and

Table II
Wire deformation in millimeters
± one standard deviation, n=4.

	1 day	7 days	28 days
NiTi	0.01±0.02	0.03±0.02	0.06±0.02
Force 1	0.03±0.02	0.03±0.03	0.08±0.03
Titanal	0.04±0.03	0.06±0.02	0.07±0.02
Align	0.05±0.04	0.06±0.02	0.07±0.02
Sentalloy medium	0.03±0.02	0.07±0.06	0.10±0.06
Nitinol SE	0.01±0.02	0.05±0.04	0.12±0.03
Reflex	0.00±0.00	0.05±0.04	0.14±0.02
Orthonol*	0.10±0.02	0.19±0.04	0.25±0.07
Nitinol*#	0.23±0.04	0.28±0.06	0.45±0.05
TMA	1.00±0.15	1.04±0.12	1.04±0.20
Permachrome stainless steel	1.25±0.04	1.29±0.04	1.32±0.03

| *indicates no significant difference between wires.*
* *indicates 1 day significantly different from 28 days;*
# *indicates 14 days different from 28 day; no other significant differences found between time periods tested.*

Ni-Ti all exhibited more deformation at the later time intervals, especially at 28 days. This suggests that the permanent deformation occurring in nickel-titanium wires was a function of time, stress relaxation.

Based on these results, three wire types (Nitinol, Nitinol SE and Ni-Ti) were tested for extended time periods. Two wires of each type were reactivated and held for an additional 28 days. When these wires were remeasured, no additional deformation was found. This held true when these same wires were again reactivated and held 28 more days (84 days total). The maximum amount of permanent deformation occurred between 14 and 28 days, for 5 mm of deflection of these 0.016" round wires. Lopez, Goldberg, and Burstone[7] concluded that Nitinol experiences an unexpected time-dependent relaxation phenomenon up to 48 hours of deflection. This study confirmed permanent deformation was a time-dependent behavior in nickel-titanium wires. The clinical significance of these changes is questionable as the greatest difference was 0.22 mm for Nitinol.

One-day deformation averages were correlated with the 28-day deformation averages. The correlation value is high ($r = .98$, $p<0.05$) indicating similar trends were present after the two test periods. The conclusion can be drawn that in further studies these wires need only be evaluated at the 1-day time interval, and not for an extended period of time. Less discrimination may result but such small differences in deformation are not clinically relevant.

Significant statistical differences were found between several of the wires, Table II. After the 1 day deflection, deformation of the stainless steel and TMA wires exhibited a statistical difference from each other and all other wires. After 1 day, the Nitinol wire was significantly different from all other wires except for the Orthonol wire. After 14 and 28 days, similar differences were found though groupings were not as straightforward. Since the 28-day test period approximates the time between orthodontic adjustments, results from this group were considered clinically relevant. The newer nickel-titanium archwires exhibited statistically less permanent deformation than the original Nitinol wire. Ni-Ti, Force 1, Titanal, Align, Sentalloy, Nitinol SE, and Reflex showed no significant differences in their means of permanent deformation after 28 days. Orthonol was significantly different from Ni-Ti, Force 1, Titanal, Align and Sentalloy but not different from Reflex or Nitinol SE. The Nitinol, TMA and Permachrome stainless steel wires were significantly different from each other and all other wires.

Discussion

This study focused on one mechanical property, permanent deformation, as a function of time. The results are relevant to the practicing orthodontist. Although there are statistically significant differences between several of the wires tested at each time interval, there is doubt whether most differences are clinically significant. The archwires tested can be considered in the following categories: Permachrome stainless steel, beta-titanium (TMA), the original Nitinol, and newer nickel-titanium wires (Orthonol, Align, Titanal, Sentalloy, Force 1, Nitinol SE, Reflex and Ni-Ti). This finding was not unexpected as several studies have previously concluded that the original Nitinol wire outperforms TMA and stainless steel wires in springback tests.[5,6,8,10,15-20]

From a clinical standpoint, only the wire deformation approaching 1 mm would be considered significant. When the large deflection (5 mm) is considered over a 28-day time interval, resulting deformation averages of 0.06 mm to 0.25 mm (newer nickel-titanium wires 28 day range) would not be clinically significant. Such small deformations are even less significant when the superior deactivation forces of nickel-titanium archwires are considered.

Proprietary manufacturing techniques and alloy contents are likely responsible for the increased elasticity of newer nickel-titanium wires. Several of the wires are promoted as being "superelastic." Such wires deliver a more constant force over a larger range of deactivation without permanently deforming.[10] Superelastic wires are superior in certain clinical situations. If one uses Miura's definition of superelasticity,[10] this test of permanent deformation does not distinguish between superelastic and nonsuperelastic wires.

The results obtained from this evaluation can be extended to other nickel-titanium wire sizes, but with caution. The same relative ranks would be expected, but more deformation would occur for larger diameter wires, and less deformation for smaller wires.

Conclusions

As a group, all the nickel-titanium archwires exhibited better springback characteristics and less permanent deformation than the beta-titanium wire, which outperformed the stainless steel wire. The newer nickel-titanium archwires exhibited less permanent deformation than the original Nitinol wire. There were no significant statistical differences between the deformation means of the newer nickel-titanium archwires, except for the Orthonol wire. From a clinical perspective, there were no relevant differences between any of the newer nickel-titanium archwires.

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