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The effect of annealing on the elastic modulus of orthodontic wires

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Abstract

Introduction: The objective of this study was to determine the effect of annealing on the elastic modulus of Nickel Titanium, Stainless Steel and Beta-titanium (TMA) wires. Different points along the wire were tested in order to determine how far from the annealed ends the elastic modulus of the wires was affected.

Methods: Eighty (80) orthodontic wires consisting of 4 equal groups (SS/TMA/Classic Nitinol®/Super Elastic Nitinol®) were used as the specimens for this study. All wires were measured and marked at 5mm measurements, and cut into 33.00mm sections. The wires were heated with a butane torch until the first 13.00mm of the wires were red hot.

Results: There was a significant difference ($F = 533.001$, $p = 0.0005$) in the change in elastic modulus for the four distances. There was also a significant difference ($F = 57.571$, $p = 0.0005$) in the change in elastic modulus for the four wire types. There was no statistical difference in the change in elastic modulus between 5mm and 10mm away from the annealed section (18mm and 23mm respectively). 2) Regardless of the wire type, no clinically important effects were seen 5mm and 10mm beyond the annealed portion.

Keywords: annealing, elastic modulus, orthodontic wires, nickel titanium, stainless steel and beta-titanium wires

Introduction

The technology involved in producing orthodontic archwires has progressed significantly since the time they were first utilized. In orthodontics, characteristics of the wires are extremely important to the success of the treatment, and wires with the correct properties should be chosen during the different stages of treatment. In the initial stages of tooth alignment, a very light wire with a low modulus of elasticity, high springback, and low constant delivery of force should be used. The modulus of elasticity is the tendency for an object to be deformed elastically when a force there is a force applied. It can also be defined as the slope of the object's stress – strain curve in the elastic deformation region (Askeland 2006) [1]. During various stages of treatment, it is important for the wire to be cinched behind the most posterior tooth to prevent the anterior teeth from flaring or allowing the wire to slip through the most posterior attachment due to deflection of the archwire during function, which can be accomplished by annealing the wires. The process of annealing occurs in stages and uses heat to make a material more workable. Heat is used to increase the rate of diffusion and provides the energy needed to break bonds. The first stage of this process, recovery, results in softening of the metal through removal of dislocations along with internal stresses. The second stage, recrystallization, occurs as new strain free grains grow to replace the grains that have been deformed by the internal stresses. Grain growth, the third stage, occurs as the microstructure begins to become more coarse, making it so the metal loses a substantial amount of its original strength (Verhoeven, 1975) [2]. In extraction cases, it is also necessary to use a wire that is rigid enough when bodily moving the teeth through the extraction spaces and to prevent tipping. The wire should also have a low coefficient of friction to allow for minimal resistance when moving the teeth during this phase of treatment. It is also important to have the correct dimension rectangular wire in place, to maintain proper torque while anterior teeth are being retracted. During the finishing stages of treatment, it is important for the wire to be formable and accept bends in order to achieve the most esthetic and functional result.

Methodology

The study was carried out in *Department of Orthodontics and Dentofacial Orthopaedics, Rishiraj College of Dental Sciences and Research Centre*. The total sample (N=80) was divided into 4 groups (Classic Nitinol®/Super-elastic Nitinol®/SS/TMA), with each group having both annealed and unannealed samples. One end of each arch wire was used for an annealed sample and one end for an unannealed sample. All of the arch wires were provided by Unitek and were0.016x.022 inch in dimension. Prior to any testing, distances of 3.00/8.00/13.00/18.00/23.00mm were measured from the end of the wire using a Carrera Precision Digital caliper and marked using a fine tipped Sharpie® marker. These marks indicated the beginning of the annealed section

(3mm), the middle of the annealed section (8mm), the end of the annealed section (13mm), 5mm past the annealed section (18mm), and 10mm past the annealed section (23mm). Load deflection tests were performed at all of these distances (8.00/13.00/18.00/23.00mm) using an Instron® machine. The load deflection test was a 3 point action at these different distances along the wires. Measurements were made only during loading and not during unloading of the specimen. The first 13mm of the end of the wires was the annealed section of the wires.

The data was plotted using a program called Test Works. The motor of the Instron machine was calibrated prior to starting each of the eight measurements for all 80 samples. Before testing, each wire was sectioned to a total length of 33mm to prevent the wire from touching anything except the 3 points being tested. This allowed the archwire to be split into annealed and unannealed sections. For each sample, the wire was placed exactly in the middle (front-to-back and side-to-side) of the test block and the crosshead was loaded to 0.1N so that it was just touching the wire. All wires were deflected to 2.5mm with a crosshead speed of0.5mm/min +/- 0.100mm/mm. For the annealed wire samples, a butane torch was used to anneal the end of the wire for a total distance of 13mm. To keep the temperature of the heat source consistent, the wires were held at a distance of 22mm from the end of the torch, while annealing. This distance was measured every time at each end of the wire prior to annealing to make sure that all parts of the wire were 22mm from the end of the torch. After each test was performed, the elastic modulus was calculated. Two points along the graph in the elastic portion were identified to indicate the slope of the curve. These points were used in order for the program to calculate the modulus of elasticity. Using this data, all unannealed values were subtracted from annealed values to determine the change in the modulus of elasticity.

Statistical analysis

A two-way analysis of variance (ANOVA) was used to determine if there were significant differences in the elastic modulus of the four wire types (Classic Nitinol®/Super-elastic Nitinol®/SS/TMA) and the four distances (8/13/18/23mm). A Tukey’s honestly significant difference (HSD) test was utilized to evaluate any differences in the levels within each independent variable. Finally, a test was completed to examine the interaction between distance and wire types. All statistical analyses were performed using the SPSS Version 21.0 statistical package. A p value of 0.05 was considered significant.

Results

Stainless Steel had the highest initial elastic modulus, which was followed by TMA and Classic Nitinol®, and finally Super Elastic Nitinol® had the lowest initial elastic modulus (See Table 1/Figure 1). This ordering of wires was the same for the annealed elastic modulus (See Table 2/Figure 2).

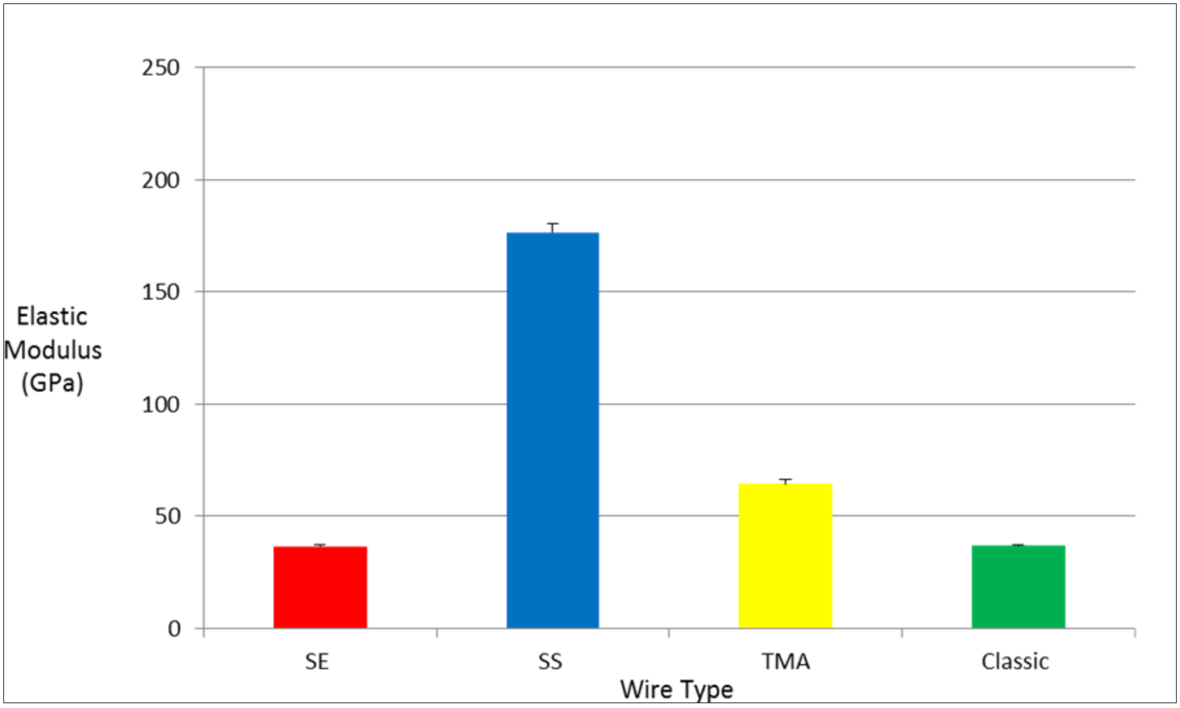

Fig 1: Initial Elastic Modulus in Different wire types

Table 1: Initial Elastic Modulus in Different Wire Types (GPa)

	Mean	SD
SE	53.44	16.74
SS	189.74	11.91
TMA	72.52	9.44
Classic	44.83	10.37

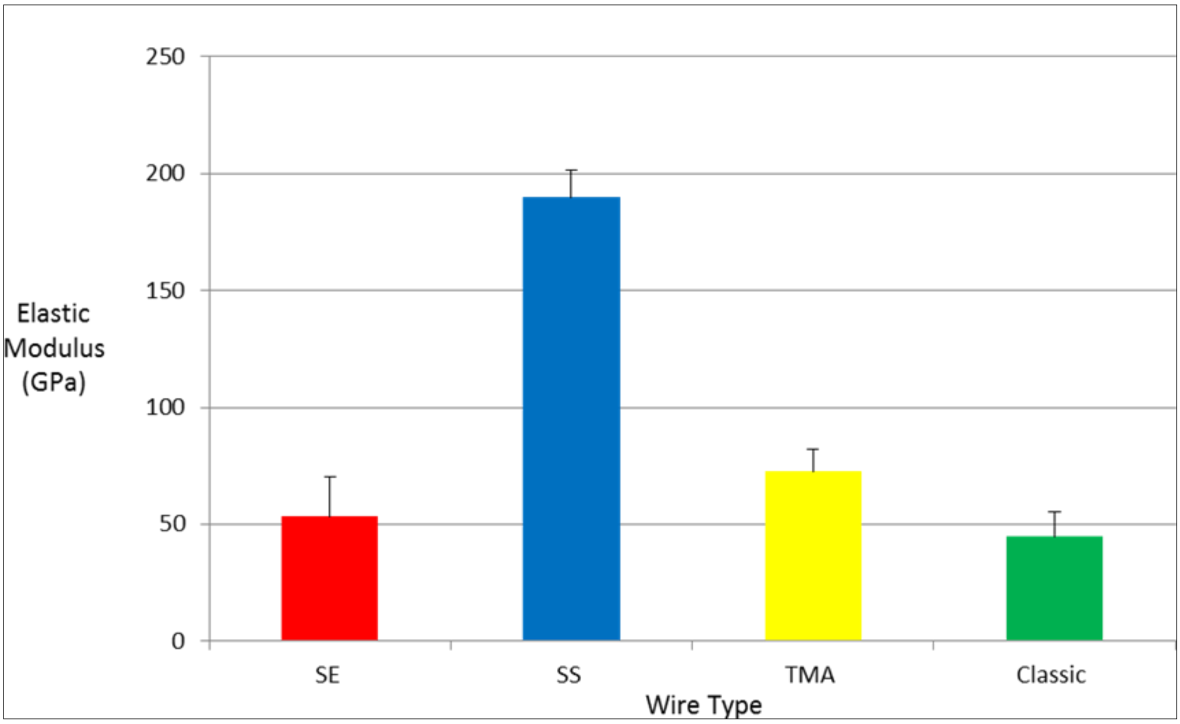

Fig 2: Annealed Elastic Modulus in Different Wire Types

Table 2: Annealed Elastic Modulus in Different Wire Types (GPa)

	Mean	**SD**
SE	36.46	0.53
SS	176.67	3.89
TMA	64.49	1.91
Classic	36.90	0.59

There was a significant difference (F = 57.571, p = 0.0005) in the change in elastic modulus (EM annealed – EM unannealed) between the four wire types (See Table 3). For Super Elastic Nitinol®, the change in EM was 16.99 +/- 17.11. This was a significantly greater change than for all other wire types. For Stainless Steel, the change in EM was 13.07 +/- 14.17. This mean change was significantly greater than for TMA and Classic Nitinol®. There was no significant difference between the change in EM for TMA (8.03 +/- 9.68) and Classic Nitinol® (7.93 +/- 10.60).

There was a significant difference (F = 533.001, p = 0.0005) in the change in elastic modulus (EM annealed – EM unannealed) between the four distances (See Table 3/Figure 3). In the middle of the annealed section (8mm), the change in EM was 26.87 +/- 11.50. This was a significantly greater increase in elastic modulus than for all other distances. At the end of the annealed section (13mm), the change in EM was 18.38 +/- 8.73. This mean change was significantly greater than for 5mm and 10mm past the annealed section (18mm and 23mm). There was no significant difference for the change in EM between 18mm (0.88 +/- 2.49) and 23mm (-0.11 +/- 2.27).

Table 3: Two way ANOVA comparing the Elastic Modulus Differences for Distance/Wire Type/and Their Interaction

Variable					
	Mean	**SD**	**F**	**p**	
Wire Type	SE	16.99^{a*}	17.11	57.571	0.0005
	SS	13.07^{b}	14.17		
	TMA	8.03^{c}	9.68		
	CLASSIC	7.93^{c}	10.60		
Distance	8	26.87^{a*}	11.50	533.001	0.0005
	13	18.38^{b}	8.73		
	18	0.88^{c}	2.49		
	23	$(-)0.11^{c}$	2.27		
Distance x Wire Type				19.601	0.0005

* - Means with different letters are significantly different

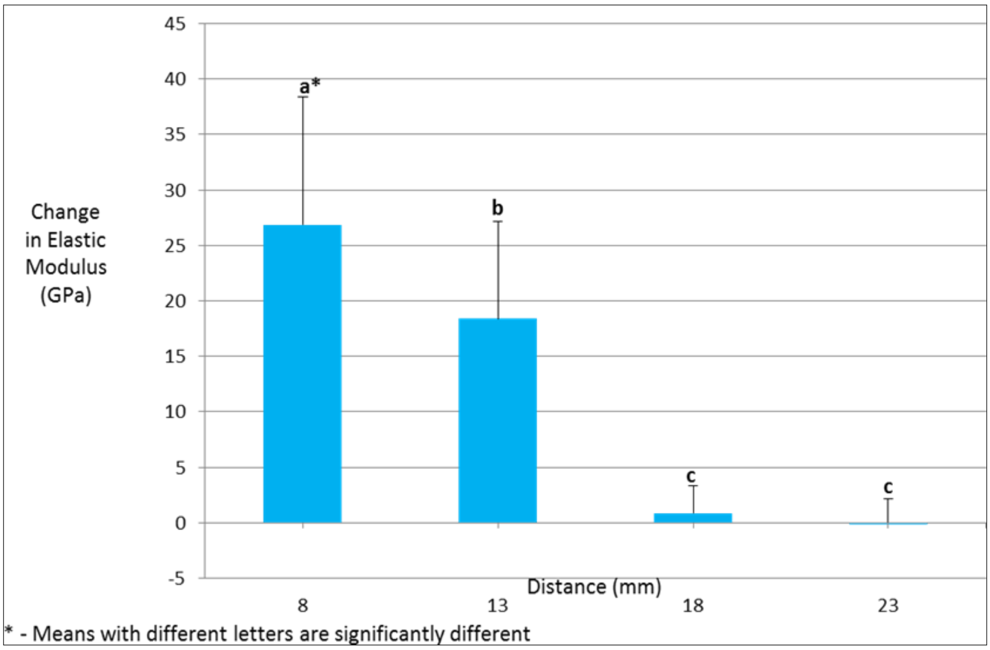

Fig 3: Change in Elastic Modulus at different Distances(mm)

There was a significant interaction (F = 19.601, p = 0.005) between the wire types and distance, however this interaction negated the differences between the wires since the changes didn't occur at all distances. The mean change in elastic modulus of the four wires was different at 8mm and 13mm (within the annealed section), but this is clinically irrelevant since this is a non-working portion of the wire. Figure 4 shows the entireinteraction between the wire types and distance Figure 4 shows the interaction that takes place between 18mm and 23mm. There is an interaction between the change in the modulus of elasticity for SS and TMA at those distances. At 18mm, SS had the greatest change in elastic modulus (1.84 +/- 3.58) and TMA had the smallest change (-0.43+/- 2.62), whereas at 23mm, SS had the smallest change in elastic modulus (-1.32 +/- 3.20) and TMA had the greatest change (0.50 +/- 2.21) (See Table 4).

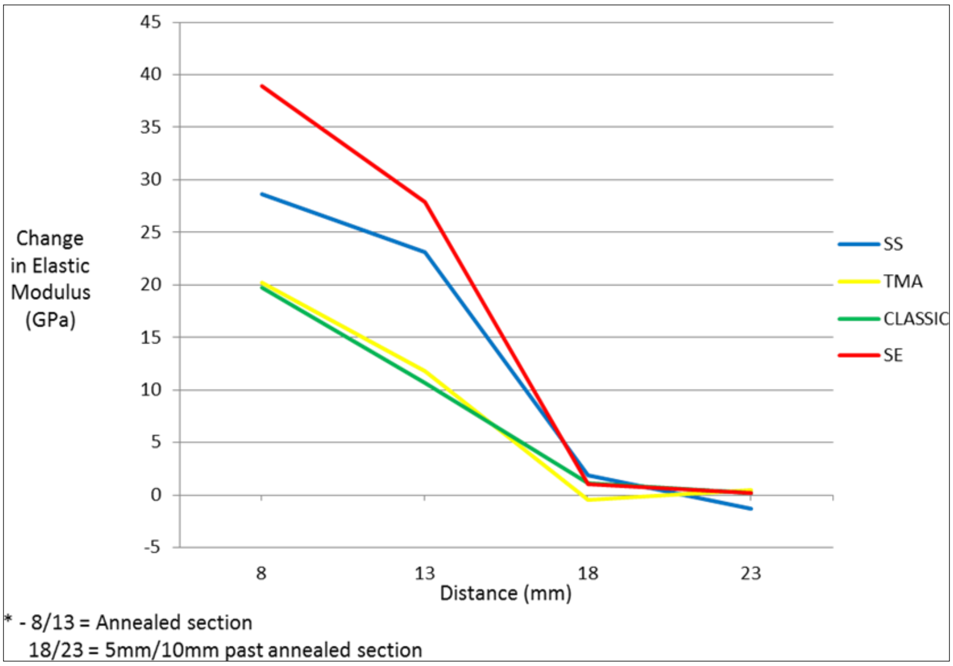

Fig 4: interaction of the change in Elastic Modulus between Distance and wire type

Table 4: Change in Elastic Modulus between Different Wire Types at Different Distances

	8mm	SD	13mm	SD	18mm	SD	23mm	SD
SS	28.61	6.40	23.16	7.41	1.84	3.58	-1.32	3.70
TMA	20.21	8.25	11.82	1.87	-0.43	2.62	0.50	2.21
CLASSIC	19.75	13.39	10.64	4.50	1.10	1.08	0.23	0.59
SE	38.89	2.49	27.91	3.15	0.99	1.47	0.15	0.61

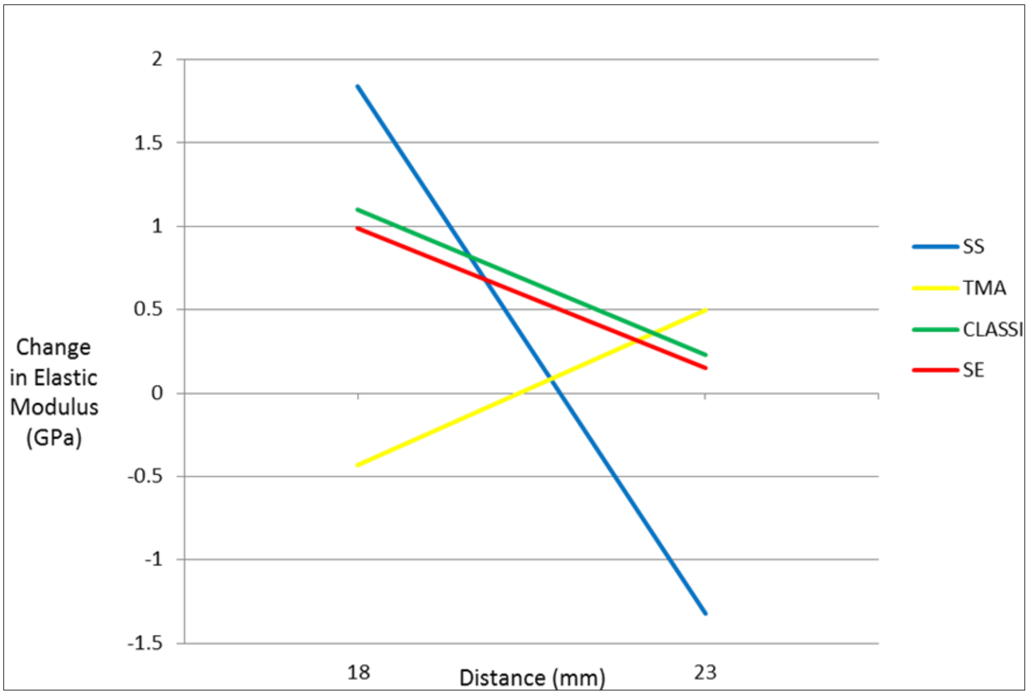

Fig 5: Concentrated view of the interaction of the change in Elastic Modulus Between distance and wire type- beyond the Annealed End (18MM and 23mm)

Discussion

This study utilized a total of 80 samples, 20 samples in each of the four wire groups. For each wire, measurements were taken within the annealed section (8mm and 13mm), and 5mm and 10mm past the annealed section (18mm and 23mm). Although there was no power analysis performed, the observed power (post hoc) was 100% for all three analyses (Distance/Wire Type/Interaction), so that N was sufficient for this study. The Partial Eta Square for distance was0.84, for wire type it was0.36, and for interaction it was0.37. Partial Eta Square is a post hoc measure of effect size. The effect size for distance (.84) was considerably larger than for wire type (.36) and their interaction (.37). Therefore, one can be more confident in the results for distance than the other two. This may be due to the effects of the significant interaction on the wire types.

Hypothesis versus Results – Distances

Although the interaction theoretically negated both significant main effects (wire type and distance), the actual interaction shown in Figure 4 and 5 shows no clinically important interaction for distance. Therefore, the significant differences found for distance are valid. In general, as the distance from the annealed end increased, the change in elastic modulus decreased. The change in elastic modulus was greater at the distances of 8mm and 13mm and decreased at the other two distances, 18mm and 23mm. Specifically, the change in elastic modulus was significantly greater at 8mm than it was at 13mm, and the change in elastic modulus was significantly greater at 13mm than it was at either 18mm or 23mm. These results confirm the first research hypothesis of this study that the change in modulus of elasticity was greater closer to the annealed end vs. further from the annealed end. There was a large difference in the change in elastic modulus between 8mm and 13mm (28.61 and 23.16 respectively, see Table 4). This is the part of the wire that is within the annealed portion and would not to be a working part of the wire since it is beyond the most posterior attachment. There was a minimal difference in the change in elastic modulus between 18mm and 23mm (1.84 and -1.32, see Table 4). A negative change in elastic modulus indicates that the elastic modulus got smaller after the annealing process. However, due to the magnitude, this difference (at 18mm and 23mm), is not a clinically important change in the elastic modulus. It should be noted that 18mm and 23mm are 5 mm and 10 mm away from the annealed portion of the wire. This suggests that the change in elastic modulus will have a minimal effect beyond the annealed section in the working part of the wire. However, these effects would have to be replicated for this result to be confirmed.

Hypothesis versus Results – Wire Type

The results of the interaction between the distance and wire type, negate the significant differences in the wire types displayed in Figure 4. The main effect results for wire type show that TMA and Classic Nitinol® had the least amount of change in elastic modulus, followed by Stainless Steel, and finally the most change occurred with Super Elastic Nitinol®. However, as mentioned previously, these results were negated because there was a significant interaction in the change of elastic modulus between the wire types tested in this study. These results confirmed the third research hypothesis that there was a significant interaction between the distance from the annealed end and the type of wire in regards to the change in modulus of elasticity (see Figure 5). However, the true interaction only took place between 18mm and 23mm, which is 5mm to 10mm away from the annealed section in the working part of the wire.

Stainless Steel, Classic Nitinol® and Super Elastic Nitinol® behaved as expected. Their change in elastic modulus decreased as the distance from the annealed section increased (from 18mm to 23mm). Stainless Steel behaved the same at these distances as the other two wires but the drop in the change in elastic modulus was much greater (from 1.84 to - 1.32). The change in elastic modulus increased for TMA as the distance from the annealed section increased (from 18mm to 23mm), but it was not clinically important (see Table 4 and Figure 4). The clinician should not be concerned about any of the wire types tested in this study when working 5mm past the annealed section due to the relatively minimal change in elastic modulus at this distance.

Clinical Implications

Even though there was a change in the modulus of elasticity 5mm and 10mm away from the annealed portion, it was determined that there would not be any clinically important effects since the change was minimal compared to the original elastic modulus.

Conclusion

Based on the results of this study we can conclude the following:

1. There are significant differences in the change in elastic modulus between the areas of the wires within the annealed section and those areas 5mm and 10mm away from the annealed section. The change in elastic modulus within the annealed section was significantly greater at 8 mm than it was at 13mm, and this was significantly greater than 18mm and 23mm (5mm and 10mm beyond the annealed section). However, there was no statistical difference in the change in elastic modulus between 5mm and 10mm away from the annealed section (18mm and 23mm respectively).
2. Regardless of the wire type, no clinically important effects were seen 5mm and 10mm beyond the annealed portion.

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