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Moments generated by simple V-bends in nickel titanium wires

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SUMMARY This study compared the moments produced by V-bends placed in rectangular nickel titanium (NiTi) orthodontic wire to those produced in titanium–molybdenum alloy (TMA). V-bends that included angles of 135, 150, and 165 degrees were heat set into 0.017 × 0.025 and 0.016 × 0.025 inch NiTi alloy wires and identical bends bent into TMA wires with a dimension of 0.018 × 0.025 and 0.016 × 0.022 inch. There were five specimens per group ($N = 60$). The moments produced by each specimen were tested on a custom jig that aligned two lower incisor brackets with zero tip or torque at an interbracket distance of 15 mm. The upper bracket was connected to a moment transducer. The V-bend position for each specimen was varied in 1 mm increments towards the moment transducer.

The moments produced by TMA wires were linear, which increased as the V-bend approached the transducer, while NiTi exhibited a non-linear curve characterized by a flattening of the moment value. The point of dissociation (where the moment experienced by the bracket became zero) was estimated for both wire types using linear mixed model analysis. For TMA wires, this point was similar to that reported in the literature but was significantly less for NiTi wire when compared with TMA. The moments produced by TMA generally increased with the magnitude of the V-bend, whereas this was not the case for NiTi.

Introduction

The mechanics generated by simple V-bends placed in orthodontic wires have previously been studied (Burstone and Koenig, 1974, 1988; Mulligan, 1980; Ronay *et al.*, 1989; Demange, 1990). The findings show that a V-bend placed equidistant between two brackets will have equal and opposite moments, without any vertical forces being generated at either bracket. As the position of the V-bend moves towards one of the brackets, the moment on that bracket increases, while those on the others decrease, and vertical forces are generated to maintain equilibrium. When the position of the V-bend is exactly one-third of the distance between the two brackets, the so-called point of dissociation is reached, where the moment on the more distant bracket is zero, and pure vertical forces only exist on that bracket (Ronay *et al.*, 1989). Further displacement of the V-bend towards the closer bracket will result in the moment on that bracket continuing to increase, with a reversal of the moment on the more distal bracket to the same direction as the larger moment on the closer bracket. The vertical forces also become numerically larger. These relationships remain valid irrespective of the interbracket distance. Furthermore, there is a linear relationship between the magnitude of the V-bend and the magnitude of the moments produced (Burstone and Koenig, 1988).

Using finite element analysis, Isaacson *et al.* (1995) concluded that V-bends near the molar teeth in a three-dimensional (3D) archwire (i.e. full arch) produced significantly less moments at the molar tooth compared with a two-dimensional system (sectional archwire) and that there was no point of dissociation where the moment at the anterior teeth changes direction, as seen in two-bracket systems. This was ascribed to the torsion effect in the wire, which leads to greater resistance to deformation in the anterior leg, and as a consequence, the point of dissociation is located more posteriorly.

V-bend analyses so far have focussed on linear elastic materials, such as stainless steel and titanium–molybdenum alloy (TMA). To date, there are no reports investigating the effect of V-bend positioning in nickel titanium (NiTi) wires. Studies have shown that NiTi T-loops that incorporate V-bends in their legs are able to produce moment to force ratios (M:F) that are capable of bodily tooth movement (Rose *et al.*, 2009) and that temperature fluctuation does not influence the M:F, although absolute values of both M and F are lower (Lim *et al.*, 2008). The aim of this study was therefore to investigate the effect of simple V-bend positioning in rectangular NiTi wire compared with TMA. The following assumptions were made for this study:

1. Moments that are generated in one plane have negligible effect on those generated out of plane (Raboud *et al.*, 1997).
2. Thermal expansion and contraction of the test apparatus are identical for all wire samples tested.

Materials and methods

A custom-made apparatus was used with two supporting arms where the superior arm held a moment transducer (Sensotec, model 34/0911-14; Sensotec, Columbus, Ohio, USA) with a fixed aluminium cap. A stainless steel twin bracket (Victory series miniature twin stainless steel bracket with 0 degrees torque and 0 degrees angulation; 3M Unitek, Monrovia, California, USA) was bonded such that the centre of the bracket coincided with the geometric centre of the transducer. The inferior arm had an identical bracket bonded to it in such a way that it was in alignment with the first bracket in all three planes, which was achieved by using a full thickness archwire as a jig. The arms were separated vertically such that the interbracket distance was 15 mm.

The V-bends were formed in straight lengths of 0.018 × 0.025 and 0.016 × 0.022 inch Japanese superelastic NiTi (Neo Sentalloy, F-100; GAC, Bohemia, New York, USA) and 0.017 × 0.025 and 0.016 × 0.022 inch TMA (Ormco, Orange, California, USA) wires. Five wire specimens of each dimension, material type (NiTi and TMA), and V-bend angle (135, 150, and 165 degrees) were used (N = 60). V-bends in the NiTi wires were set by clamping the wire around stainless steel pins on a steel template at the desired angle and heating them to 510°C for 9 minutes in a crown furnace (Ivoclar programat P90, Schaan, Liechtenstein; Miura *et al.*, 1990).

The V-bend wire specimens were inserted in the brackets and held by elastomeric modules (Alastic; 3M Unitek). The V-bend for each specimen was initially positioned at a distance of 2 mm from the fixed lower bracket and then progressively moved towards the upper bracket that was attached to the moment transducer in 1 mm increments, until a distance of 13 mm was reached from the lower bracket. Distances, after wire placement, were measured with a digital calliper (MD 25; Mitutoyo, Kawasaki, Japan) from a fine yellow bristle-marked line on the wire to the lower bracket. Each measurement was repeated twice by a single operator (JJ) and the average was used.

The apparatus was placed in a thermostatically controlled insulated oven (model 76J-1; RFL Industries Inc., Boonton, New Jersey, USA) with an electric fan to evenly distribute the heat. Ambient air temperature was measured by two digital thermocouple thermometers placed on each side of the chamber. Once the average temperature had reached the desired temperature of 36.0 ± 0.5°C, the moment was measured and recorded. The temperature was maintained using the oven thermostat (coarse control) and a 60 W incandescent light bulb (fine control). The wire was disengaged from the lower bracket after each incremental recording to minimize the fatigue effect.

The moment transducer was calibrated at the selected temperature by suspending known weights from aluminium arms on either side of the transducer. The recordings of the calculated moment produced a direct linear relationship (R^2 > 0.997). Linear regression equations were calculated (Excel 2000; Microsoft, Redmond, Washington, USA) to convert the moment transducer output readings into grams per millimetre.

The Stata statistical program (Version 9; Stata Corporation, College Station, Texas, USA) was used to analyse the curves generated by the TMA and NiTi wires. A quadratic model was used to approximate the curves for the NiTi wires and a linear model for the TMA wires The statistical linear mixed model allowed for differences in each bend angle, material type, wire thickness, multiple measurements with each wire, position of V-bend, and amount of curvature. The statistical models were used to obtain an estimate of where the fitted lines crossed the x-axis, and as such, there was difficulty in determining confidence intervals around these extrapolated estimates.

Results

The effect of V-bend position in the two alloy materials of different thickness is graphically summarized in Figure 1a–1d. For all wires, the moment increased as the V-bend approached the transducer: for TMA, this was largely linear, whereas for NiTi, the curve was initially linear and then tended to flatten off.

The x-axis intercept was calculated to be 4 mm for all TMA wires combined, which equated to an interbracket ratio of 0.27. For all NiTi wires combined, the x-axis intercept was determined as 0.5 mm, which is a ratio of 0.033.

Analysis of the slopes of the curves indicated that all TMA graphs were linear in nature and that the magnitude of the slope increased three times in approximate proportion to the increase of the V-bend i.e. 150 degree (30 degree external angle) curves were twice that of the 165 degree (15 degree external) bend and the 135 degree (45 degree external). This did not hold for NiTi wires, where only the 165 degree curve was significantly different from the others within each size of wire.

Discussion

The linear graphs obtained for TMA wires were consistent with a previous study that examined pre-activated T-loops (Lim *et al.*, 2008). The graphs for NiTi wires with V-bends were non-linear and exhibited a flattening of the curve characteristic of the alloy, except for the 0.018 × 0.025 inch 165 degree V-bend wire (15 degree external angle, i.e: shallow bend). The flattened curve for the NiTi wires was also consistent with previous investigations using pre-activation bends in NiTi T-loops (Rose *et al.*, 2009). A possible explanation for the more linear curve observed for the 0.018 × 0.025 inch 165 degree V-bend wire is the possible effect of the wire's relatively large cross-sectional area combined with a low angle V-bend, which may not have allowed stress-induced martensitic (SIM) transformation to

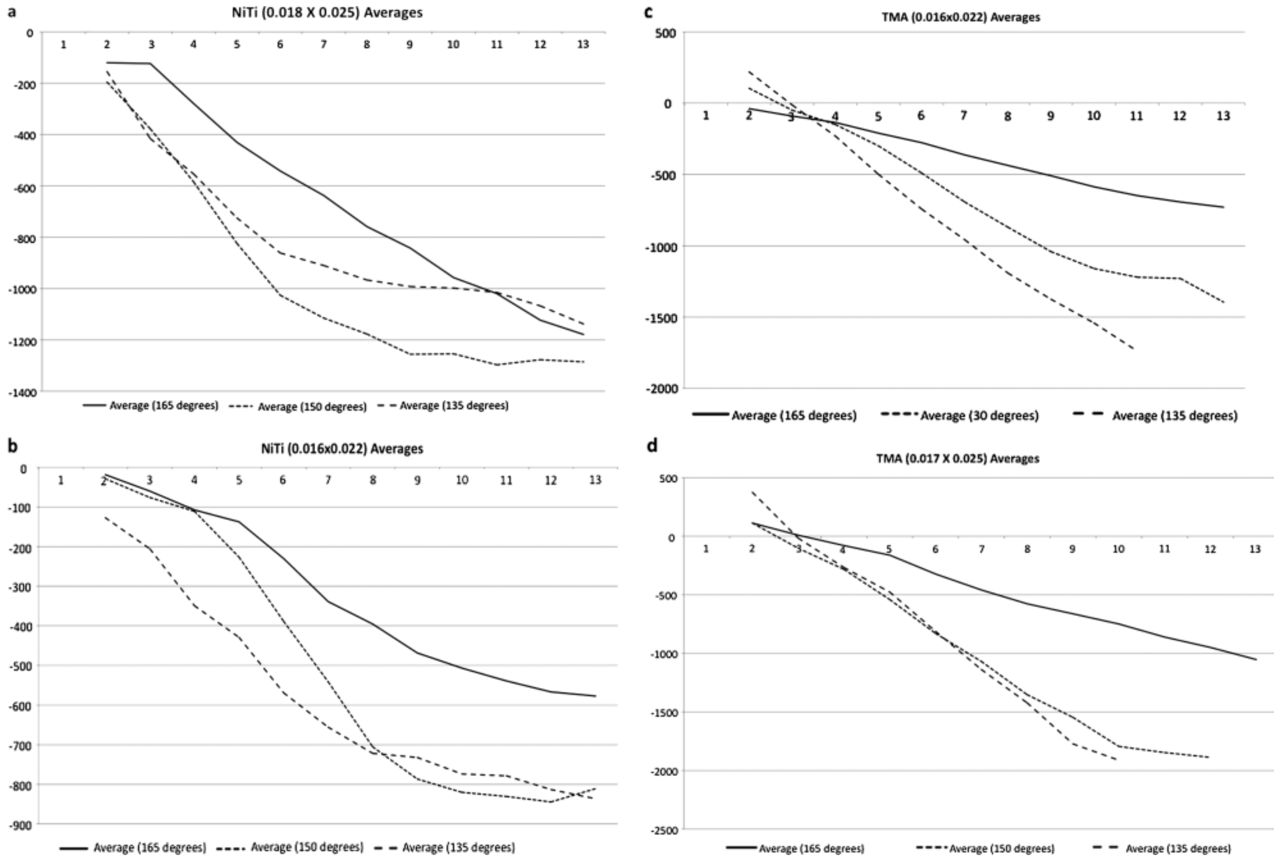

Figure 1 Graphs illustrating the average moment value (*y*-axis, in grams per millimetre) obtained as the V-bend position approaches the moments transducer, situated at 15 mm (*x*-axis, in millimetre) away from the origin. Each line represents the average of five wire specimens. (a) Nickel titanium (NiTi) 0.018 × 0.025 inch, (b) NiTi 0.016 × 0.022 inch, (c) titanium–molybdenum alloy (TMA) 0.016 × 0.022 inch, and (d) TMA 0.017 × 0.025 inch.

occur, thus producing the linear curve of a stable austenitic phase alloy. As the V-bend increased to 150 degrees and above, it would appear that SIM occurred, with superelastic transformation being exhibited.

As mentioned previously, the vertical dimensions of the larger NiTi wire were greater than the TMA that it was compared with (0.018 versus 0.017 inch). The stiffness of a wire is affected by the Young's modulus of elasticity and the cross-sectional area of the wire, and in this instance, the larger dimension of the NiTi was offset by a lower modulus of elasticity. Furthermore, the aim of the research was not to compare specific wire sizes against each other but to establish material specific characteristics.

Previous analytical studies have shown that points of dissociation for TMA take place at 0.33 of the interbracket distance (Burstone and Koenig, 1974, 1988; Ronay *et al.*, 1989). The results of the present study largely support these findings, with an average point of dissociation located at a distance ratio of 0.27. There are a number of factors that can account for this slight difference, which arise largely as a result of the practical versus the hypothetical: the V-bend is in reality not a single point but a curve in the wire that is difficult to position precisely; the hypothetical analysis assumes that the wires are free to slide (Burstone and Koenig, 1988), whereas in reality, there is friction between the wire and the bracket and the elastomeric module. In addition, there is a potential error in the bracket alignment due to flexibility of the system, as well as measurement of error, although this was reduced by duplicate measurements by a single operator.

The point of dissociation of the NiTi wires was significantly smaller than for the TMA wires, with a calculated X-intercept value of 0.5 mm, which equates to a distance ratio of 0.033 between the brackets. This is 10-fold closer to the bracket than for TMA, and clinically, this point would be practically at the site of the posterior attachment. Extrapolating this further, this implies that a V-bend in a NiTi wire will produce opposite moments for any position of the V-bend between the brackets except for when the V-bend is within 0.5 mm of either bracket, at which point the moment on the longer arm will approach zero. These findings suggest that a simple V-bend in a NiTi wire will nearly always produce opposite moments at either end of a two-tooth geometry and that the magnitude of the moment on the larger side will exhibit a superelastic effect once the threshold for SIM is reached.

Conclusions

The following conclusions can be drawn from the study:

1. Moments produced by V-bends in NiTi wires do not show a linear relationship as the V-bend approaches the bracket.
2. The point of dissociation for TMA wires is similar to the one-third interbracket distance previously reported.
3. The point of dissociation for NiTi wires is significantly closer to the bracket compared with TMA wires.
4. Sequential increases in V-bend magnitude in NiTi wires do not produce proportional increases in moments, as observed in TMA wires.

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References

Burstone C J, Koenig H A 1974 Force systems from an ideal arch. American Journal of Orthodontics 65: 270–289

Burstone C J, Koenig H A 1988 Creative wire bending—the force system from step and V bends. American Journal of Orthodontics and Dentofacial Orthopedics 93: 59–67

Demange C 1990 Equilibrium situations in bend force systems. American Journal of Orthodontics and Dentofacial Orthopedics 98: 333–339

Isaacson R J, Lindauer S J, Conley P 1995 Response of 3-dimensional arch wires to vertical V-bends: comparisons with existing 2-dimensional data in the lateral view. Seminars in Orthodontics 1: 57–63

Lim Y, Quick A, Swain M, Herbison P 2008 Temperature effects on the forces, moments, and moment to force ratio of nickel-titanium and TMA symmetrical T-loops. Angle Orthodontist 78: 1035–1042

Miura F, Mogi M, Okamoto Y 1990 New application of super-elastic NiTi rectangular wire. Journal of Clinical Orthodontics 24: 544–548

Mulligan T F 1980 Common sense mechanics. Journal of Clinical Orthodontics 14: 336–342

Raboud D W, Faulkner M G, Lipsett A W, Haberstock D L 1997 Three-dimensional effects in retraction appliance design. American Journal of Orthodontics and Dentofacial Orthopedics 112: 378–392

Ronay F, Kleinert W, Melsen B, Burstone C J 1989 Force system developed by V bends in an elastic orthodontic wire. American Journal of Orthodontics and Dentofacial Orthopedics 96: 295–301

Rose D, Quick A, Swain M, Herbison P 2009 Moment to force ratio characteristics of preactivated NiTi and TMA symmetrical T-loops. American Journal of Orthodontics and Dentofacial Orthopedics 135: 757–763