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A comparative assessment of the forces and moments generated with various maxillary incisor intrusion biomechanics

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SUMMARY The aim of this study was to comparatively evaluate the intrusive forces and buccolingual torquing moments generated during anterior maxillary intrusion using different maxillary incisor intrusion mechanics. Five wire specimens were used for each of the following intrusive arches: blue Elgiloy utility arch 0.016 × 0.016 inch, TMA utility arch 0.017 × 0.025 inch, Burstone TMA intrusion arch 0.017 × 0.025 inch, and reverse curve of Spee NiTi 0.016 × 0.022 inch. The wires were inserted on bracketed dental arches constructed on maxillary Frasaco models, segmented mesially to the maxillary canines. Simulated intrusion from 0.0 to 3 mm was performed using the orthodontic measurement and simulation system (OMSS), and forces and moments were recorded in the sagittal plane at 0.1 mm vertical displacement increments. All measurements were repeated five times for each specimen and values recorded at 1.5 mm for all wires were used for statistical evaluations. The results were analysed with one-way analysis of variance with forces and moments serving as the dependent variables and wire type as the independent variable. *Post hoc* multiple comparisons were performed using the Tukey test (0.05 error rate).

Comparison of the two major intrusion techniques for the maxillary anterior teeth, segmented and bioprogressive, revealed that the Burstone TMA 0.017 × 0.025 inch intrusion arch exerted the lowest force on the incisors (0.99 N), followed by the TMA utility 0.017 × 0.025 inch (1.33 N) and the blue Elgiloy 0.016 × 0.016 inch utility (1.43 N). The highest force was recorded for the reverse curve of Spee NiTi and exceeded the value of 9 N. The lowest buccolingual moments were recorded with the Burstone intrusion arch (2.47 Nmm), whereas the highest was registered for the utility arch constructed with a 0.017 × 0.025 inch TMA wire (7.31 Nmm).

Introduction

Orthodontic intrusion of the anterior dentition is indicated for the management of a deep overbite, especially in subjects where bite opening with eruption of posterior teeth is contraindicated. The functional evaluation of the upper gingival line in relation to the upper lip indicates whether the maxillary or mandibular anterior teeth should be intruded (Zachrisson, 1998; Sarver, 2001).

Two major orthodontic intrusion techniques for the maxillary anterior dentition have been developed: the segmented arch (Burstone, 1962, 1966, 1977) and the bioprogressive (Ricketts, 1976; Ricketts *et al.*, 1979). Both use intrusion arches with anchorage on posterior teeth but with different wire composition, shape, and point of force application. Additionally, the introduction of reverse curve of Spee NiTi archwires allowed for an alternative method of incisor intrusion.

Currently, a few clinical trials have evaluated variables such as side-effects (Otto *et al.*, 1980; McFadden *et al.*, 1989; Costopoulos and Nanda, 1996; van Steenbergen *et al.*, 2004, 2006), force magnitude (Goerigk *et al.*, 1992; van Steenbergen *et al.*, 2005a), and application point of the intrusive force (van Steenbergen *et al.*, 2005b) for the bioprogressive or the segmented arch techniques. A limited number of studies have also compared the segmented (Weiland *et al.*, 1996) or Ricketts (Dake and Sinclair, 1989) technique with a continuous archwire technique, whereas one study focused on incisor intrusion in patients with marginal bone loss using both techniques (Melsen *et al.*, 1989). Nonetheless, there is a lack of evidence on the quantitative assessment of forces and moments of intrusion systems, especially the effect of reverse curve NiTi archwires on the anterior segment of the maxillary dental arch.

The aim of this study was to comparatively evaluate the intrusive forces and torquing moments generated during anterior maxillary intrusion between the various intrusion techniques.

Materials and methods

Experimental apparatus and configuration

The orthodontic measurement and simulation system (OMSS) was used for the *ex vivo* evaluation of the different intrusion mechanics (Bourauel *et al.*, 1992). The OMSS is based on the principle of the two-tooth model and allows the measurement of all forces and moments acting on two regions simultaneously. For this purpose, the OMSS has two stepping motor-driven positioning tables equipped with force/moment transducers, monitored by a personal computer that controls the measurements. Measurements are recorded of the forces–moments generated by an orthodontic appliance, when the positioning tables are moved along a specified path (Drescher *et al.*, 1991).

An acrylic Frasaco model was constructed for the maxillary jaw, with an ideal, levelled, and aligned, dental arch. The first and second molars on the model were bonded with 0.018 inch slot tubes with 0 degrees angulation/torque/distal offset and 0.018 inch slot brackets were placed on the rest of the teeth (Forestadent, Pforzheim, Germany). Each model was split into two segments after bracket placement: the anterior segment, which included the four incisors and the posterior segment, which included the teeth from the canine to the first molar. An appropriate adaptor was fixed on each of these model segments in order to make them mountable on the positioning tables of the OMSS (Figure 1). A straight 0.018 × 0.025 inch stainless steel archwire was subsequently ligated to the two segments and they were both mounted on the positioning tables of the OMSS. An adjustment of the system was conducted with the straightwire in place, so that all forces–moments generated were nullified in this configuration.

In the absolute measurement mode, the dental arch was initially levelled. During the measurement procedure for the utility and the Burstone intrusion arches, the anterior segment was gradually extruded up to 3 mm and afterwards intruded to its initial position. The forces/moments generated in the anterior segment were measured three dimensionally in 0.1 mm steps. During the measurement cycle for the reverse NiTi arches, the extrusion path of the anterior positioning table was reduced to 1.5 mm in order to avoid bracket failure due to the high magnitudes of forces and moments generated with 3 mm activation.

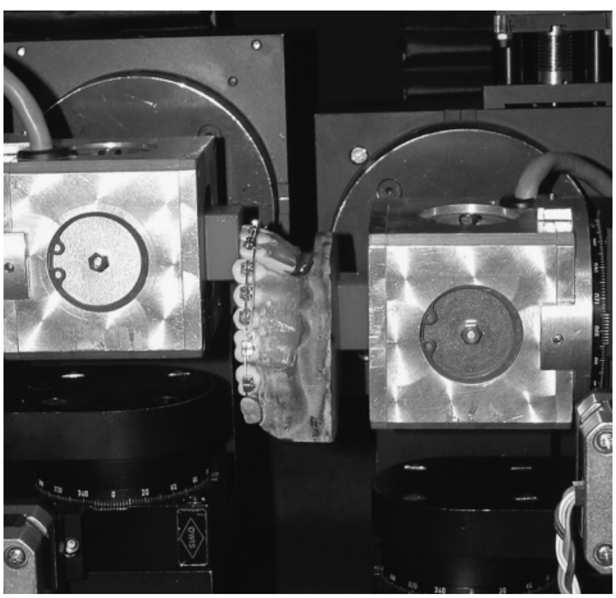

Figure 1 The acrylic Frasaco model mounted on the positioning tables of the orthodontic measurement and simulation system.

Materials

The following intrusion arches were evaluated with the absolute measurement system, as regards the forces–moments generated in the anterior maxillary segment:

1. Utility arch 0.016 × 0.016 inch Blue Elgiloy® [Rocky Mountain Orthodontics (RMO), Denver, Colorado, USA)].
2. A utility arch constructed with a 0.017 × 0.025 inch TMA® (Ormco, Glendora, California, USA).
3. Burstone intrusion arch constructed with 0.017 × 0.025 inch TMA® (Ormco), ligated distal to the lateral incisors, and gingivally of the anterior sectional wire.
4. Reverse curve of Spee NiTi 0.016 × 0 .022 inch (Nitinol SE, RMO).

Five utility and five Burstone intrusion arches were fabricated by the first author for each of the above-mentioned combinations. Additionally, five prefabricated reverse curve NiTi archwires were used on the maxillary arch. Each of the wire specimens was used five times; during the measurements of the NiTi wires, the temperature in the OMSS chamber was kept constant at 36.6°C.

The segmented intrusion arches were constructed according to the specifications given by Burstone (1977). The 3 mm helix of the intrusion arch was wound and placed mesial to the molar tube. The diameter of the helix was measured with a digital calliper (Mitutoyo, Japan), and a 45 degree molar tip-back was incorporated in to the wire, whereas the intrusion arch was ligated gingivally to the anterior segmented arch. The posterior segment consisted of both molars and premolars on each side, which were stabilized with a sectional passive 0.018 × 0.025 inch stainless steel wire. An anterior, passive sectional arch from the same wire was fabricated for stabilization of the incisors. A palatal–lingual arch was not deemed necessary since the posterior segments of the model were united. The utility arches were fabricated with a 45 degree molar tip-back, as described by Ricketts (1976) and Ricketts *et al.* (1979), without, for simplicity, any molar rotation or buccal root torque incorporated in the wire. During the experimental intrusion, the helix of the Burstone archwires was ligated to the tube and the utility/NiTi archwires were cinched back. The length of the buccal bridge of the utility arches, calculated as the distance between the anterior and posterior vertical steps, was 28 mm and the distance between the proximal surfaces of the canine and lateral incisor brackets was 4 mm.

For the objectives of this study, which targeted pure intrusive and buccolingual torque components of the intrusion configurations, only intrusive forces (Fx) and moments (My; anterior buccolingual torque) were used for the final evaluations of simulated intrusion. The remaining force (Fy, Fz) and moment (Mx, Mz) components are greatly affected by factors such as correct adjustment of the anterior segment relative to the posterior segment, degree of symmetry between the two sides, proper archwire insertion, ligation, and activation. Since all the aforementioned factors introduce unnecessary variability and confound the results, which are of real interest during anterior maxillary intrusion, the components Fy, Fz, Mx, Mz were adjusted to zero and therefore not included in the analyses. For the utility and Burstone configurations, intrusion was performed from 0.0 to 3.0 mm whereas for the NiTi reverse curve archwire, the intrusion was confined from 0.0 to 1.5 mm. For consistency and comparability, data analysis for all intrusion configurations was performed using the values at 1.5 mm.

Statistical analysis

The data were statistically analysed by means of one-way analysis of variance (ANOVA). Forces and moments were the dependent variables and wire type the independent variable. *Post hoc* multiple comparisons were performed using the Tukey test (0.05 error rate). Statistical analysis was undertaken with the Statistical Package for Social Sciences (version 15.0 SPSS Inc., Chicago, Illinois, USA).

Results

Wire type was a significant predictor for the forces and moments generated by the various wires as indicated by ANOVA (Tables 1 and 2). The utility and the Burstone maxillary archwires recorded mean intrusive forces in the range of 1–1.4 N, whereas the reverse curve NiTi delivered mean force in excess of 9 N, all at 1.5 mm intrusion.

Table 1 Analysis of variance of intrusion force versus wire type.

Intrusion force (N)	Sum of squares	df	Mean square	*F*	Significance
Between groups	1219.853	3	406.618	22220.445	0.000
Within groups	1.757	96	0.018		
Total	1221.609	99			

Table 2 Analysis of variance of moments (torque) versus wire type.

Moments (Nmm)	Sum of squares	df	Mean square	*F*	Significance
Between groups	314.937	3	104.979	73.369	0.000
Within groups	137.360	96	1.431		
Total	452.296	99			

Figure 2 depicts the range of intrusion forces (Fx) per wire type and vertical displacement from 0.0 to 1.5 mm (0.1 mm increments). The force levels recorded for the 0.016 × 0.022 inch reverse curve NiTi were approximately six times greater than those produced by the other configurations at the 1.5 mm level (Table 3).

Moment (My) ranking for the wire groups showed a notable difference compared with that of the intrusion force (Table 4 and Figure 3). The highest mean was found for the 0.017 × 0.025 inch TMA utility (7.3 Nmm) and the lowest for the Burstone TMA intrusion system (2.4 Nmm). The 0.016 × 0.016 Elgiloy and the reverse curve NiTi exhibited similar magnitudes, in the order of 6 Nmm.

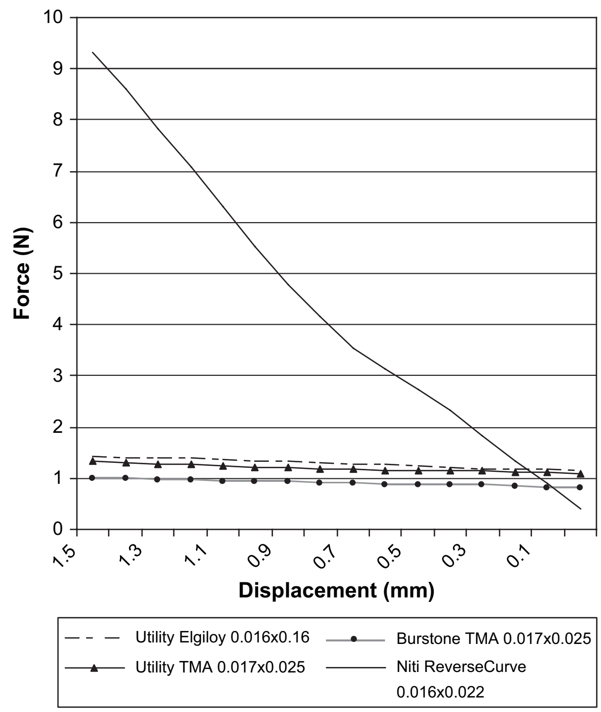

Figure 2 Intrusion force (Fx) per wire type and displacement for a range of 1.5 mm (0.0–1.5 mm) at 0.1 mm increments.

Table 3 Intrusion force results of the systems included in the study.

Wire type	Intrusion force (N)		
	Mean	Standard deviation	Tukey grouping*
Burstone TMA 0.017 × 0.025	0.99	0.11	A
Reverse curve NiTi 0.016 × 0.022	9.31	0.27	B
Utility Blue Elgiloy 0.016 × 0.016	1.43	0.07	C
Utility TMA 0.017 × 0.025	1.33	0.12	D

*Means with the same letter are not significantly different at the 0.05 level.

Table 4 Intrusion moment results for the systems included in the study.

Wire type	Moments (Nmm)		
	Mean	Standard deviation	Tukey grouping*
Burstone TMA 0.017 × 0.025	2.47	1.44	A
Reverse curve NiTi 0.016 × 0.022	5.69	1.05	B
Utility Blue Elgiloy 0.016 × 0.016	5.92	0.96	B
Utility TMA 0.017 × 0.025	7.31	1.28	C

*Means with the same letter are not significantly different at the 0.05 level.

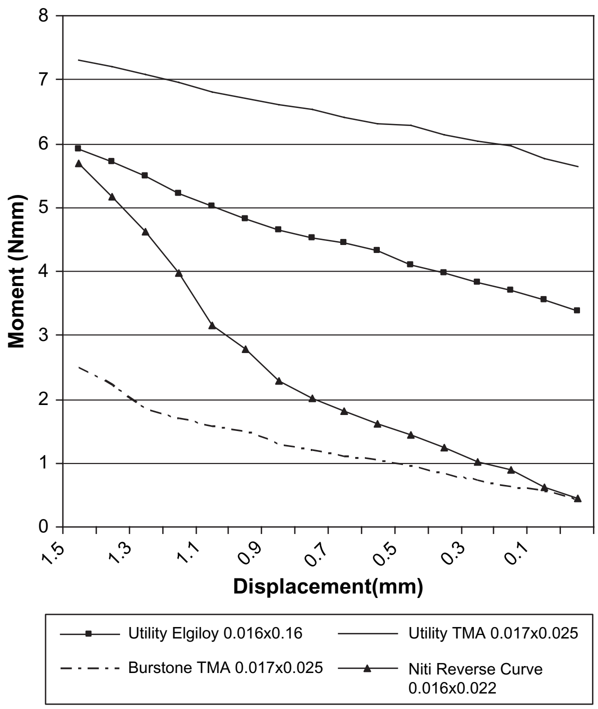

Figure 3 Buccolingual moments (My) per wire type and displacement for a range of 1.5 mm (0.0–1.5 mm) at 0.1 mm increments.

Discussion

The use of Elgiloy wire possesses two potential advantages over stainless steel wire: it is produced in four tempers with different degrees of hardening, whereas the Blue Elgiloy presents the best formability and the lowest yield strength from the four tempers (Kusy *et al.*, 2001) and after initial wire shaping, heat treatment increases the yield point and the strength of the Co–Cr wire and the softest temper becomes equivalent to regular stainless steel (Kapila and Sachdeva, 1989; Johnson, 2003). The moduli of elasticity (*E*), however, of Blue Elgiloy and stainless steel are similar, as well as their force delivery (Kusy and Greenberg, 1981; Kusy, 1983) and perhaps this might be the reason for the lack of attractiveness of Co–Cr wires (Kusy *et al.*, 2001). In the present experimental simulation of maxillary incisor intrusion, the non-heat-treated 0.016 × 0.016 inch Blue Elgiloy utility arch exerted higher intrusive forces than the 0.017 × 0.025 TMA utility and the 0.017 × 0.025 TMA Burstone intrusion arch.

The *E* of the β–Ti wires is around 40 per cent of that of stainless steel but still twice that of NiTi (Kapila and Sachdeva, 1989). These wires deliver approximately half the amount of force compared with that of stainless steel (Burstone and Goldberg, 1980) or Co–Cr wires (Kapila and Sachdeva, 1989) of comparable cross-sections and equal amounts of activation. The increase in stiffness accompanying an increase in cross-section from 0.016 × 0.016 inch to 0.017 × 0.025 inch of the same composition is about 86 per cent (Thurow, 1982). For a rectangular supported beam, the situation is more complex. Its dimension in the direction of bending is the primary determinant of its properties and the increase in beam size affects strength in a cubic function. Additionally, if the ends are tightly anchored, i.e. are not allowed to slide freely, the beam presents higher stiffness (Proffit and Fields, 2000). In this experiment, the utility Blue Elgiloy 0.016 × 0.016 exerted 8 per cent more intrusive force relative to the utility TMA 0.017 ×0.025, which, in turn, produced 34 per cent more force than the Burstone TMA 0.017 × 0.025 intrusion arch. The latter showed the lowest intrusive forces from the configurations tested due to the presence of a 3 mm helix which increased wire length, and because it was not tightly anchored to the anterior segment.

The intrusive forces recorded for the reverse curve 0.016 × 0.022 inch NiTi were the highest of all arches tested. This is a continuous arch and the force magnitude is primarily determined by factors such as the size of and the distance between the canine and lateral incisor brackets (Halazonetis, 1998). In the simulation employed in this study, with only 1.5 mm supraeruption of the incisors, the force that this continuous arch exerted on the anterior segment was 9.3 N. It has been suggested that some light rectangular wires with low moduli of elasticity could be used even during the early stages of treatment (Burstone, 1981; Kapila and Sachdeva, 1989) but although the initial magnitude of this force is expected to decrease rapidly during tooth movement, the use of a continuous reverse curve rectangular Nitinol arch in an unlevelled dental arch should be avoided.

The magnitude of the intrusive force applied on the four upper incisors was initially suggested to be around 1 N (Burstone, 1977); the 0.017 × 0.025 TMA intrusion arch exerted forces within this range. On the other hand, Ricketts *et al.* (1979) proposed a magnitude of 1.25–1.6 N, and the utility arches that were measured were in that range. With respect to the lower incisors, both Burstone (1977) and Ricketts *et al.* (1979) agreed that the force should be approximately half the amount used for the upper incisors. Nevertheless, a recent clinical study demonstrated that 0.4 N of force could intrude the four maxillary incisors at the same rate as those of double the magnitude (Van Steenbergen *et al.*, 2005a).

Regarding the buccolingual moments, the lowest values were recorded for the Burstone intrusion arch, a statically determined force system. This wire was not ligated into the slots but the location of the point of force application in relation to the centre of resistance of the anterior segment can alter the axial inclination of that segment (Van Steenbergen *et al.*, 2005b). Between the utility archwires, the lowest values were recorded for the Blue Elgiloy. The torsional play of 0.016 × 0.016 Blue Elgiloy wire in a 0.018 slot is 27 degrees. It follows that a 35–48 degree twist should be applied in order to obtain 20 Nmm of torsional moment (Meling and Odegaard, 1998). Generally, and if the wire material/manufacturer remain the same, the increase of the cross-section from 0.016 × 0.016 to 0.017 × 0.025 reduces the slack by two-thirds (Meling *et al.*, 1997). TMA presented lower torsional stiffness values in comparison with Blue Elgiloy and the 0.017 × 0.025 TMA utility arch produced about 24 per cent higher torquing moments than the 0.016 × 0.016 Blue Elgiloy utility arch.

In the present experiment, the reverse curve Nitinol wire could not be directly compared with the other wire types since this was the only continuous archwire. At the initial levelled situation, the geometry between canine and lateral incisor brackets resembled the Class VI type but during supraeruption of the incisor segment, it changed to a Class I geometry since these two teeth had no angulation but were at a different occlusogingival level (Burstone and Koenig, 1974; Halazonetis, 1998). Clinically, the moments created by this configuration are expected to tip the teeth rapidly, thus changing the whole system in a way that is difficult to predict. The unpredictable nature of this force system is perhaps the main contraindication to the use of these wires.

A limitation of this research, as well as of most *ex vivo* investigations, relates to the difficulties in extrapolating clinical relevance. The OMSS is based on the principle of the two-tooth model and closely resembles the clinical situation where initial tooth mobility, occlusal interferences, etc. may be adjusted for; however, the OMSS may not account for factors such as intraoral ageing and the influence of saliva. Furthermore, it has not yet been possible to predict the centre of resistance of the four incisors, and the intrusion of these teeth should be carefully monitored in order to avoid side-effects.

Conclusions

The intrusive forces exerted by continuous reverse curve NiTi wires on incisors exceeded 9 N and thus are beyond biologically safe limits. Therefore, the use of such archwires in a 1.5 mm vertical discrepancy of a dental arch is not indicated. Comparison of the two major intrusion techniques for the anterior teeth, i.e. the segmented and bioprogressive techniques, revealed that the Burstone TMA 0.017 × 0.025 intrusion arch exerted the lowest force on the incisors (0.99 N), followed by the utility TMA 0.017 × 0.025 and the utility with Blue Elgiloy 0.016 × 0.016 the highest (1.43 N).

The lowest moments in the sagittal plane were recorded with the Burstone intrusion arch, whereas the highest was registered for the utility arch constructed with a 0.017 × 0.025 TMA wire.

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