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A comparative assessment of forces and moments generated by lingual and conventional brackets

Iosif Sifakakis*, Nikolaos Pandis**,***, Margarita Makou*, Christos Katsaros***, Theodore Eliades**** and Christoph Bourauel*****

*Department of Orthodontics, School of Dentistry, University of Athens, **Private Practice, Corfu, Greece, ***Department of Orthodontics and Dentofacial Orthopedics, School of Dentistry, University of Bern, Switzerland, ****Department of Orthodontics, School of Dentistry, Aristotle University of Thessaloniki, Greece and *****School of Dentistry, University of Bonn, Germany

Correspondence to: Theodore Eliades, 57 Agnoston Hiroon, Nea Ionia 14231, Greece. E-mail: teliades@ath.forthnet.gr

SUMMARY The aim of this study was to assess the effect of bracket type on the labiopalatal forces and moments generated in the sagittal plane. Incognito™ lingual brackets (3M Unitek), STb™ lingual brackets (Light Lingual System; ORMCO), and conventional 0.018 inch slot brackets (Gemini; 3M Unitek) were bonded on three identical maxillary acrylic resin models, with a palatally displaced right lateral incisor. The transfer trays for the indirect bonding of the lingual brackets were constructed in certified laboratories. Each model was mounted on the orthodontic measurement and simulation system and ten 0.013 inch CuNiTi wires were used for each bracket type. The wire was ligated with elastomerics and each measurement was repeated once after re-ligation. The labiopalatal forces and the moments in the sagittal plane were recorded on the right lateral incisor. One-way analysis of variance and *post hoc* Scheffe pairwise comparisons were used to assess the effect on bracket type on the generated forces and moments. The magnitude of forces ranged from 1.62, 1.27, and 1.81 N for the STb, conventional, and Incognito brackets, respectively; the corresponding moments were 2.01, 1.45, and 2.19 N mm, respectively. Bracket type was a significant predictor of the generated forces ($P < 0.001$) and moments ($P < 0.001$). The produced forces were different among all three bracket types, whereas the generated moments differed between conventional and lingual brackets but not between lingual brackets.

Introduction

The patients' interest in aesthetically pleasing orthodontic appliances has risen during the last decades and the appliances offering this advantage are preferred, especially among adult patients. The scientific evidence in this field has become stronger in recent years, although not in an analogous way to the demand for these appliances. The removable transparent appliances still have some limitations in the spectrum of dental movements: bodily tooth movement required in premolar extraction patients is difficult to achieve and the degree of accomplished extrusion or rotation could not be accurately predicted (Baldwin *et al.*, 2008; Kravitz *et al.*, 2009). A lingual appliance is a treatment alternative, which was formerly associated with higher bracket failure rate, complex bonding technique, adaptation difficulties of the patient to the appliance, and longer treatment duration (Kurz and Romano, 1998). Nowadays, the bonding accuracy does not seem to differ between lingual and labial systems (Shpack *et al.*, 2007), whereas recently developed lingual systems (Wiechmann *et al.*, 2003) offer fully customized appliances with more built-in information. These brackets have an extended base for greater bond strength and a lower profile, a fact that enhances patient comfort in comparison with prefabricated lingual braces (Stamm *et al.*, 2005).

The labial and lingual orthodontic approaches are quite different in their biomechanical principles. The decrease in the interbracket distance at the anterior region in lingual appliances increases the relative stiffness of an archwire three times for first- and second-order bends and 1.5 times as for third order (Moran, 1987). High stiffness provides forces of higher magnitude, a less constant force over time as the appliance experiences deactivation, and a relatively difficulty in accurately applying a given force (Kapila and Sachdeva, 1989). Additionally, the point of force application and the line of force relative to the centre of resistance are different in lingual and labial orthodontics, a fact that could substantially influence tooth movements (Geron *et al.*, 2004).

The aim of this study was to assess the effect of bracket type between lingual and conventional appliances on the labiopalatal forces and the moments generated in the sagittal plane.

Materials and methods

Experimental apparatus

The orthodontic measurement and simulation system (OMSS) was used for the *ex vivo* evaluation of the different brackets (Bourauel *et al.*, 1992). This experimental

apparatus allows the measurement of the force systems acting in two different regions three dimensionally (Drescher *et al.*, 1991). Two force/moment sensors appropriately connected with the regions in question, receive the signal, and transduce it to a personal computer, which calculates the tooth movement with the aid of a mathematical model. Two motorized positioning tables, adjustable in six axes, are connected with the computer and consequently execute the calculated movement. The force system could be measured at the initial position, as well as during the simulation movement.

Configuration and materials

Three different bracket types were evaluated: Incognito™ lingual brackets (3M Unitek, Monrovia, Minnesota, USA), STb™ lingual brackets (Light Lingual System, ORMCO), and conventional stainless steel 0.018 inch slot brackets (Gemini, 3M Unitek). Polyvinylsiloxane impressions of the initial malocclusion with a palatally displaced right lateral incisor (Figure 1) were sent to certified laboratories in order to construct the transfer trays for the indirect bonding of the lingual brackets (Incognito Laboratory, Bad Essen, Germany and AOA Orthodontic Laboratory, Sturtevant, Wisconsin, USA). Additionally, three identical maxillary models of the initial malocclusion were constructed from acrylic resin. Each model was bonded with brackets up to the first/second premolars from each bracket type. Both lingual bracket types had a 0.018 inch slot. The Incognito brackets had a vertical slot at the anterior region (Wiechmann *et al.*, 2003), in contrast with the STb brackets, whose slots were horizontal. The latter bracket system had 0 degree angulation, high torque at the anterior region (+55 degrees), and standard torque (+11 degrees) at the premolars. The conventional brackets were bonded on the centre of each tooth mesio-distally and at the suggested height with the aid of a Unitek bracket positioning gauge (3M Unitek). The specifications of the conventional brackets were the following: upper central incisor torque 0 degree and angulation 10 degrees, upper lateral incisor torque 7 degrees and angulation 8 degrees, upper cuspid torque 14 degrees and angulation 5 degrees, and upper bicuspid torque −7 degrees and angulation 0 degree.

At the initial malocclusion, a passive 0.018 × 0.025 inch archwire was constructed for each of the models. The palatally displaced right lateral incisor was consolidated and each one of these two model segments was mounted on the positioning tables of the OMSS with an appropriate adaptor. The initial position of the segments was ensured transferred during the OMSS mounting with the passive 0.018 × 0.025 inch archwire. At this point, an adjustment of the system was conducted with the passive wire in place and all forces/moments generated were nullified.

Ten specimens of 0.013 CuNiTi (STb Social 6 Optimal Force; ORMCO) were used for each bracket type. The archwire was ligated with 0.120 inch (Short Sticks; ORMCO) elastomeric ligatures into the STb and conventional brackets and with German overties with one element of a power chain (Power Chain I; ORMCO) in Incognito brackets (Figure 2). The reverse double overties (German overties) provide for almost complete insertion by nearly fully engaging the archwire into the bracket slots (Fuck *et al.*, 2005). Each measurement was repeated once after re-ligation. The labiopalatal forces and the moments in the sagittal plane were recorded on the right lateral incisor. The OMSS during the measurement cycles was installed in a temperature-controlled chamber (VEM 03/400, Vötsch Heraeus, Germany) at a constant temperature of 37°C, which reasonably approximates the intra-oral temperature (Moore *et al.*, 1999).

Statistical analysis

For each specimen, the mean of the two repeated measurements was calculated and used for the analysis of

Figure 1 The initial malocclusion with a palatally displaced right lateral incisor.

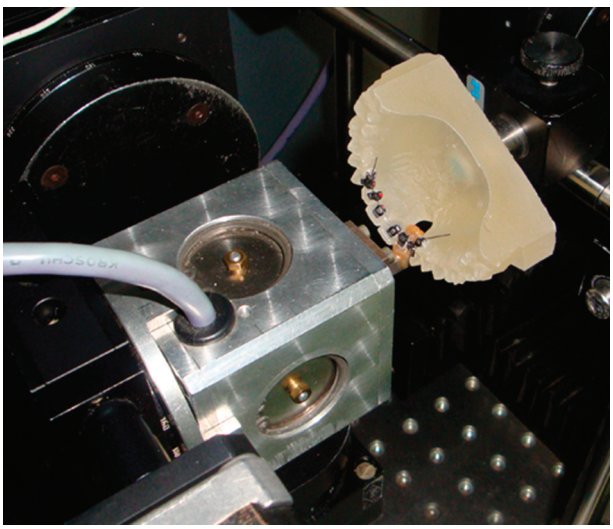

Figure 2 The acrylic resin model mounted to the positioning tables of the orthodontic measurement and simulation system.

the data. Mean values and standard deviations of the forces and moments generated were calculated per bracket type. One-way analysis of variance (ANOVA) and *post hoc* Scheffe pairwise comparisons were conducted to assess the effect of bracket type on the generated forces and moments. All statistical analyses were performed with the Stata 11 (Stata Corp., College Station, Texas, USA).

Results

The mean (standard deviations) generated forces for STb, conventional, and Incognito brackets were 1.62 (0.07), 1.27 (0.05), and 1.81 (0.06) N, respectively. The corresponding moments were 2.01 (0.19), 1.45 (0.42), and 2.19 (0.43) Nmm (Table 1). From the ANOVA tables (Tables 2 and 3), it is obvious that bracket type was a significant predictor of the generated forces ($F = 212.67$, $P < 0.001$, adjusted $R^2 = 0.94$) and moments ($F = 11.20$, $P < 0.001$, adjusted $R^2 = 0.41$).

The *post hoc* Scheffe pairwise comparisons (Table 1) have indicated that the produced forces were different among all three bracket types, whereas the generated moments differed between conventional and lingual brackets but not between lingual brackets.

Table 1 Mean values and standard deviation (SD) of the labiopalatal force (Newton) and sagittal moment (nanomillimetre) on the displaced lateral incisor between the different bracket systems.

	Force mean (SD)	Moment mean (SD)
Conventional	1.27 (0.05)^{A}	1.45 (0.42)^{A}
STb	1.63 (0.07)^{B}	2.01 (0.19)^{B}
Incognito	1.81 (0.06)^{C}	2.20 (0.43)^{B}

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

Table 2 Analysis of variance table for the effect of bracket type on the generated labiopalatal forces on the displaced lateral incisor.

Source	Partial sum of squares	Degrees of freedom	Mean square	F	Probability > F
Model	1.5099	2	0.7549	212.67	0.0000
Bracket	1.5099	2	0.7549	212.67	0.0000
Residual	0.9585	27	0.0035		
Total	1.6057	29	0.0553		

Table 3 Analysis of variance table for the effect of bracket type on the generated moments in the sagittal plane on the displaced lateral incisor.

Source	Partial sum of squares	Degrees of freedom	Mean square	F	Probability > F
Model	2.9644	2	1.482	11.20	0.0003
Bracket	2.9644	2	1.482	11.20	0.0003
Residual	3,574	27	0.133		
Total	6.539	29	0.2254		

Discussion

The experimental investigations of the initial force system produced by lingual appliances are scarce. Regarding the force magnitude, it is anticipated that an archwire of the same dimension and composition would exert higher forces at the anterior region if ligated lingually since the wire stiffness is increased (Moran, 1987). The bending stiffness of a beam is inversely proportional to the cube of length and the torsional stiffness is inversely proportional to length (Thurow, 1982). Moreover, the decrease in stiffness for bending is proportional to the cube of interbracket width increase (Creekmore, 1976). In the present experiment, the forces measured on the lateral incisor for the STb and Incognito brackets were 23 and 38per cent higher relative to conventional brackets, respectively. It is more difficult to apply light optimal forces with lingual brackets since the load/deflection rate is increased in comparison with conventional appliances (Moran, 1987; Geron *et al.*, 2004). The difference between the two lingual systems could be attributed to the interaction of the ligation mode with the different slot designs. In case of the Incognito lingual brackets, the archwire was ligated with German overties, which provide maximum seating force, and the vertical walls of the slot provided additional stabilization to the archwire in the horizontal plane. The effect of the German overties onto the archwire stabilization is expected to be less pronounced in thinner archwires and minor tooth displacements since in these cases, the seating force for the wire is expected to be lower.

The moment created from a force applied lingually may produce a tooth movement much more complicated and unpredictable. Theoretically, the moments created from a horizontal force could be the same between the two bracket systems if force magnitude remains the same and if the vector of the force remains on the same horizontal plane and consequently on the same distance from the centre of resistance. This explains the similar patterns of tooth displacement at horizontal loadings observed between labial and lingual systems in a three-dimensional finite element model of an upper incisor (Jost-Brinkmann *et al.*, 1993). In the present experimental set-up, the alteration in the point of force application, labial or lingual, and the differences in force magnitude have additive actions on the magnitude of the initial moments in the sagittal plane. As a result, these moments were higher in both lingual appliances (Figure 3). The difference in force magnitude between the two lingual appliances was not capable to establish a statistically significant difference between the moments measured from these appliances. This implies that the distance between the force vector and the centre of resistance

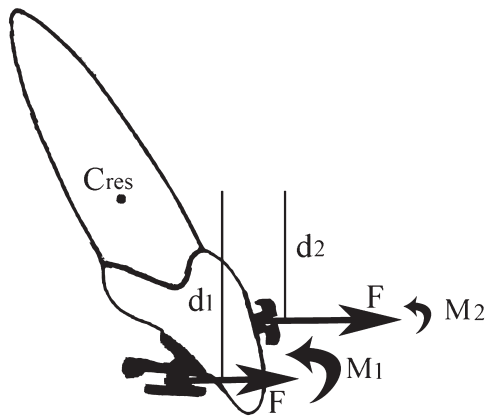

Figure 3 The alteration in the point of force application—labial or lingual could influence the magnitude of the moments in the sagittal plane.

in Incognito brackets was smaller in comparison to the STb brackets.

By contrast to the horizontal forces, vertical forces of the same magnitude produce moments that differ significantly between the two bracket systems due to the differences in the distances of the force vectors from the centre of resistance. These moments are always smaller as compared with a labial bracket. In extreme cases, such as in a retroclined maxillary incisor, the resulting moment is in an opposite direction. In this case, an intrusion force applied lingually could aggravate the inclination of that tooth (Geron *et al.*, 2004).

The last component of the force system at the bracket is the couple created from a rectangular archwire. The rotational tendency by the moment of this couple at the lingual brackets manifests irrespective of the location of the bracket on the tooth (Isaacson *et al.*, 1993) and was not encountered in the present experimental set-up.

The force magnitude for tipping movement should not exceed 0.36 N for an anterior or 0.72 N for a posterior tooth and similar values are required for extrusion or rotation; twice as much force would be required for bodily tooth movement (Proffit and Fields, 2000). Although higher forces were used in certain experimental protocols in humans (Ren *et al.*, 2003), effective tooth movement can be produced with lower forces too with the benefit of reduction in the volume of root resorption (Iwasaki *et al.*, 2000; Paetyangkul *et al.*, 2009). In the light of this evidence, the magnitude of the forces measured in this experiment could skeptically be considered as biologically acceptable. The initial magnitude of this force is expected to decrease rapidly during tooth movement but even in case of the labial brackets, the mean force on the displaced lateral incisor was 1.27 N. At least for the Incognito System, the clinician has the choice to use a thinner customized 0.012 inch superelastic (SE) Niti for the first archwire. This wire is thermally reprogrammed during the bending process (Wiechmann *et al.*, 2003). After this treatment, it is certainly not as stiff as a normal, over the counter, 0.012 inch SE Niti.

A recent experimental investigation evaluated the force system generated by the Incognito system in comparison with a conventional labial system (Fuck *et al.*, 2005). This comparison revealed that the lingual system generated similar forces at the anterior region but higher forces at molars, smaller moments at the frontal plane and higher moments at the horizontal plane. A relative wide conventional bracket was used for his comparison since it left 55 per cent of the wire length free between the brackets. The free length of the archwire that was left between the rather narrow Incognito brackets was 76 per cent.

The OMSS model resembles very closely the clinical situation but conclusions regarding clinical performance should be drawn with skepticism. Factors, such as intra-oral ageing and saliva, which influence the resulting force system, are disregarded by the machine. Furthermore, it has not yet been possible to predict accurately the centre of resistance in every tooth and the force systems measured at the bracket cannot be used directly to predict future movement of teeth since various factors affect the transfer of the bracket force system to the centre of resistance (Halazonetis, 1998). Consequently, the movement of teeth should be carefully monitored to avoid side effects. Further research should focus on the reduction of the force magnitude of the initial archwires, especially in lingual bracket systems. Additionally, it would be clinically interesting to evaluate more archwire types regarding the generated force system as well as in malpositions in the vertical plane.

Conclusions

A 0.013 inch CuNiTi archwire generated high initial forces in the horizontal plane on a displaced lateral incisor; higher force magnitude was found for the lingual brackets. Between the two lingual systems, the lowest force was recorded at the brackets with the horizontal slot and the highest for the system tied with German overties.

The lowest moment measured in the sagittal plane was recorded at the conventional brackets, where no difference was found between the two types of lingual brackets.

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