European Journal of Orthodontics 35 (2013) 375–380
doi:10.1093/ejo/cjs029
Advance Access publication 9 May 2012

A comparative assessment of torque generated by lingual and conventional brackets

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SUMMARY The aim of this study was to assess the effect of bracket type on the labiopalatal moments generated by lingual and conventional brackets. Incognito™ lingual brackets (3M Unitek), STb™ lingual brackets (Light Lingual System; ORMCO), In-Ovation L lingual brackets (DENTSPLY GAC), and conventional 0.018 inch slot brackets (Gemini; 3M Unitek) were bonded on identical maxillary acrylic resin models with levelled and aligned teeth. Each model was mounted on the orthodontic measurement and simulation system and 10 0.0175 × 0.0175 TMA wires were used for each bracket type. The wire was ligated with elastomerics into the Incognito, STb, and conventional brackets and each measurement was repeated once after religation. A 15 degrees buccal root torque (+15 degrees) and then a 15 degrees palatal root torque (−15 degrees) were gradually applied to the right central incisor bracket. After each activation, the bracket returned to its initial position and the moments in the sagittal plane were recorded during these rotations of the bracket. One-way analysis of variance with *post hoc* multiple comparisons (Tukey test at 0.05 error rate) was conducted to assess the effect on bracket type on the generated moments. The magnitude of maximum moment at +15 degrees ranged 8.8, 8.2, 7.1, and 5.8 Nmm for the Incognito, STb, conventional Gemini, and the In-Ovation L brackets, respectively; similar values were recorded at −15 degrees: 8.6, 8.1, 7.0, and 5.7 Nmm, respectively. The recorded differences of maximum moments were statistically significant, except between the Incognito and STb brackets. Additionally, the torque angles were evaluated at which the crown torque fell well below the minimum levels of 5.0 Nmm, as well as the moment/torque ratio at the last part of the activation/deactivation curve, between 10 and 15 degrees. The lowest torque expression was observed at the self-ligating lingual brackets, followed by the conventional brackets. The Incognito and STb lingual brackets generated the highest moments.

Introduction

Torque causes the twist of a beam or a wire and torsion is the actual twisting that takes place in the material, generating shear strains and shear stresses, as the result of the torque. Orthodontic torque refers to the buccolingual root tipping in which movement of the crown is minimized and movement of the root apex is maximized (Thurow, 1982). A force from a round archwire acting on a bracket introduces a rotational moment of a magnitude which depends upon the magnitude of the force and its distance from the centre of resistance. A rectangular archwire creates additionally a couple of forces in the bracket slot, which has a rotating effect that can be expressed as a moment. The rotational tendency by the moment of this couple manifests irrespective of the location of the bracket on the tooth (Isaacson *et al.*, 1993). Torque expression is affected by several factors concerning either the archwire or the bracket. These factors include the dimensions and material properties of the archwire and the bracket, the angle of twist of the archwire relative to the brackets, the mode of ligation, and the relative bracket placement as related to tooth morphology (Germane *et al.*, 1989; Morina *et al.*, 2008; Huang *et al.*, 2009; Archambault *et al.*, 2010).

Torque expression in lingual appliances is not adequately investigated. It is stated that the lingual tooth aspect is more complex and versatile and therefore, every change in the bracket position on the lingual side may cause unpredictable and extensive change in the torque and vertical tooth height. Additionally, the distance between the centre of resistance and point of force application could be different between lingual and conventional appliances and this influences the magnitude of the moments of forces. As a consequence, torque is more difficult to control in lingual orthodontics (Stamm *et al.*, 2000; Geron *et al.*, 2004; Knösel *et al.*, 2009).

The aim of the present study was to assess the effect of bracket type between lingual and conventional appliances on the torque generated in the sagittal plane on a central incisor from a rectangular archwire.

Materials and methods

Experimental apparatus

The orthodontic measurement and simulation system (OMSS) was used for the simulation of the torque at an upper central incisor (Bourauel *et al.*, 1992). This experimental apparatus, developed at the University of Bonn, allows the quantitative evaluation of different biomechanical orthodontic systems (Drescher *et al.*, 1991). The six component force/moment sensors are appropriately connected with the region in question, receive the signal, and transduce it to a personal computer, which calculates the tooth movement with the aid of a mathematical model. The six axes positioning tables are connected with the computer and consequently execute the calculated movement. This configuration allows the complete registration of the force–torque vectors three dimensionally and the desirable movement of the measurement regions freely in space.

Configuration and materials

Four different bracket types were evaluated: Incognito™ lingual brackets (3M Unitek, Monrovia, CA, USA), STb™ lingual brackets (Light Lingual System; ORMCO, Orange, CA, USA), In-Ovation L lingual brackets (DENTSPLY GAC, Bohemia, NY, USA), and conventional stainless steel 0.018 inch slot brackets (Gemini Twin; 3M Unitek). All lingual bracket types had a 0.018 inch slot. Incognito is a customized bracket system with preset torque specifications. These brackets have a vertical slot with vertical insertion direction at the anterior region (Wiechmann *et al.*, 2003), in contrast with the STb and In-Ovation L brackets, whose slots were horizontal. The STb bracket system had 0 degrees angulation, high torque at the anterior region (+55 degrees) and standard torque (+11 degrees) at the premolars. The In-Ovation L bracket system had 0 degrees angulation, +60 degrees torque at the anterior region, and +10 degrees torque at the premolars. The specifications of the conventional brackets were the following: upper central incisor torque 14 degrees and angulation 5 degrees, upper lateral incisor torque 7 degrees and angulation 8 degrees, upper cuspid torque 0 degrees and angulation 10 degrees, and upper bicuspid torque −7 degrees and angulation 0 degrees.

Four identical maxillary models of the final set up model of an orthodontic patient were constructed from acrylic resin and each model was bonded with brackets up to the second premolars from each bracket type. With the aid of the final, ideal 0.0182 × 0.0182 inch TMA customized archwire constructed by the certified laboratory (Incognito Laboratory, Bad Essen, Germany); each series of lingual brackets was bonded passively on a model. The Incognito brackets were bonded according to the template, received from the laboratory. The same archwire was used to bond the rest of the lingual brackets on the middle of the tooth surfaces. A torque–force sensor of the OMSS replaced the right central incisor (Huang *et al.*, 2009) and the bracket was bonded directly on the sensor (Figure 1). The preparation of the model with the conventional brackets was similar, with the aid of a passive 0.018 × 0.025 inch stainless steel archwire. At this configuration, an adjustment of the system was conducted with the above mentioned archwire in place and all forces/moments generated were nullified.

Ten specimens of 0.0175 × 0.0175 TMA (ORMCO) were evaluated in each bracket type, which were constructed ideally on the template that accompanied the 0.0182 × 0.0182 inch TMA customized archwire by one of the authors. The archwires were ligated with 0.120 inch (Short Sticks; ORMCO) elastomeric ligatures into the Incognito, STb, and conventional brackets. A 15 degrees buccal root torque (+15 degrees) and then a 15 degrees palatal root torque (−15 degrees) was gradually applied to the right central incisor bracket, in steps of 0.5 degree along the central axis of the slot. After each activation, the bracket returned to its initial position and the moments in the sagittal plane were recorded during these rotations of the bracket. Each measurement was repeated once after religation. The measuring range of the torquing moments in OMSS was ±450 Nmm and the torque threshold 0.2 Nmm. The OMSS during the measurement cycles was installed in a temperature-controlled chamber (VEM 03/400, Vötsch Heraeus, Germany).

Statistical analysis

From the two repeated measurements in every specimen, the mean was calculated and used in the statistical analysis

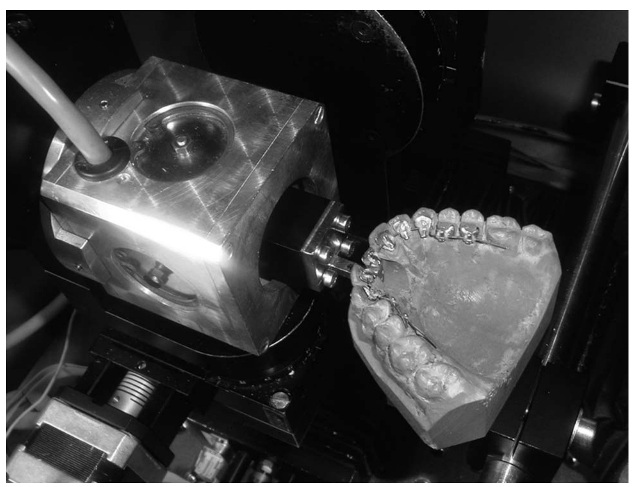

Figure 1 The torque–force sensor of the orthodontic measurement and simulation system replaced the right central incisor and the bracket was bonded directly on the sensor.

of the data. Additionally, the mean between the two angular measurements, recorded during buccal, and palatal root torque application, at which the torquing moment fell bellow the limit of 5.0 Nmm was evaluated. For the evaluation of the slope, the two parts of every curve—buccal and palatal root torque—were combined and the mean torque was calculated between 10 and 15 degrees, both during activation and during deactivation.

One-way analysis of variance with *post hoc* multiple comparisons (Tukey test at 0.05 error rate) were conducted for all three analyses. All Statistical analyses were performed with the Stata 12 (Stata Corp, College Station, Texas, USA).

Results

The moment–angle curves for each bracket type are depicted on Figures 2–Figures 5. The mean (standard deviations) generated moments at maximum rotation points (±15 degrees) for the different bracket types are shown in Table 1. The magnitude of maximum moment at +15 degrees was 8.8, 8.2, 7.1, and 5.8 Nmm for the Incognito, STb, conventional Gemini, and the In-Ovation L brackets, respectively; similar values were recorded at −15 degrees: 8.6, 8.1, 7.0, and 5.7 Nmm. The recorded differences of maximum moments were statistically significant, except between the Incognito and STb brackets.

Table 2 depicts the angular rotation (degrees) at which the torquing moment fell bellow the limit of 5.0 Nmm. During activation, at Incognito brackets, this point was reached at an earlier angular level (9.4 degrees), followed by the STb (11.0 degrees) and Gemini (12.3 degrees) brackets. The In-Ovation L brackets delivered 5.0 Nmm at 13.9 degrees. A similar pattern was recorded during deactivation.

The mean slope (moment/torque ratio) during the last linear part of the curves, between 10 and 15 degrees, was calculated for each bracket type. The Incognito brackets showed the highest ratio, followed by the STb and Gemini brackets. The lowest ratio was recorded at In-Ovation L brackets, during the activation, as well as the deactivation phase.

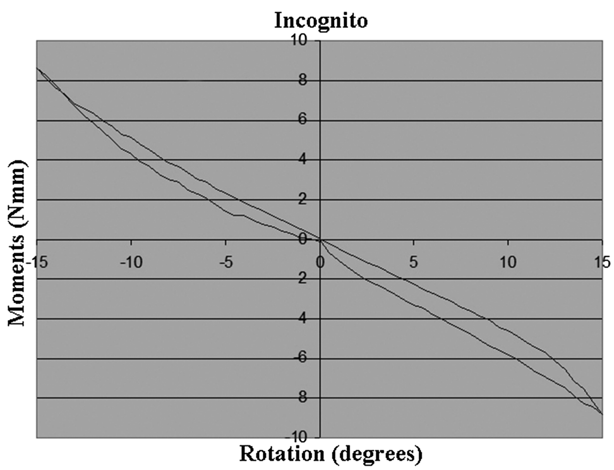

Figure 2 Moment–angle curve for the Incognito lingual bracket system during the activation and deactivation phase.

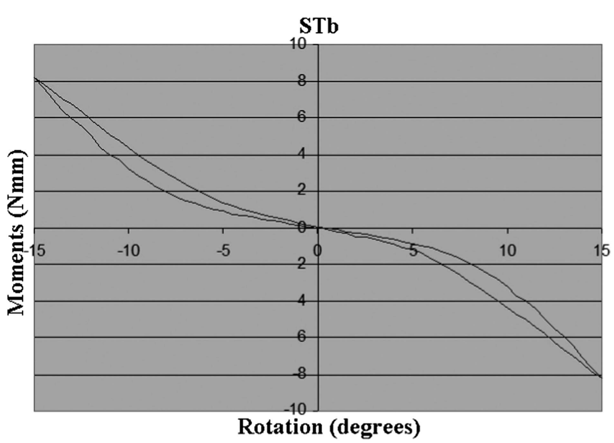

Figure 3 Moment–angle curve for the STb lingual bracket system during the activation and deactivation phase.

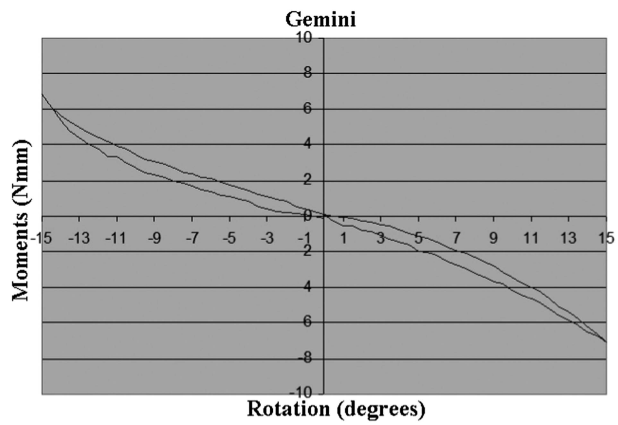

Figure 4 Moment–angle curve for the Gemini labial bracket system during the activation and deactivation phase.

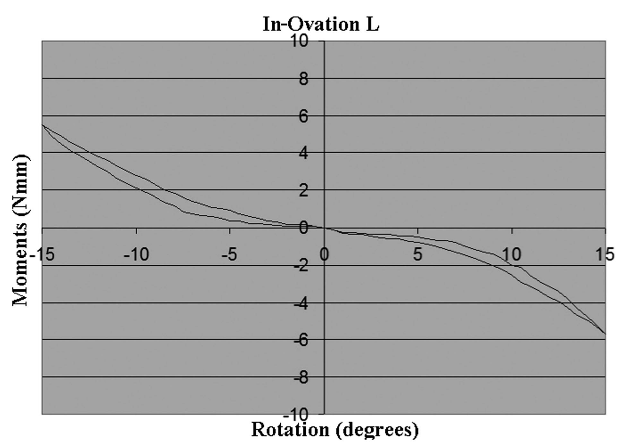

Figure 5 Moment–angle curve for the In-Ovation L lingual self-ligating bracket system during the activation and deactivation phase.

Table 1 Mean values and standard deviation (SD) of the labiopalatal moment (Nmm) on the displaced central incisor between the different bracket systems.

Maximum moments at ±15° rotation—mean (SD)		
	+15°	−15°
In-Ovation-L[a]	5.8 (0.29)	5.7 (0.22)
Incognito[b]	8.8 (0.63)	8.6 (0.42)
STb[b]	8.2 (0.72)	8.1 (0.73)
Gemini[c]	7.1 (0.51)	7.0 (0.21)

Same letter indicates non-statistical difference between brackets (Tukey pairwise comparisons).

Table 2 Mean values and standard deviation (SD) of the angular rotation (°) of the displaced central incisor at ±5.0 Nmm torque level between the different bracket systems.

Rotation at moment ±5.0 Nmm—mean (SD)		
	+5.0 Nmm	−5.0 Nmm
In-Ovation-L[a]	13.9 (0.55)	14.1 (0.34)
Incognito[b]	9.4 (1.11)	10.1 (1.17)
STb[c]	11.0 (0.90)	11.4 (0.76)
Gemini[d]	12.3 (0.24)	12.6 (0.53)

Same letter indicates non-statistical difference between brackets (Tukey pairwise comparisons).

Discussion

The present experiment evaluated the moment of the couple of forces created from a rectangular archwire in a levelled arch during the rotation of a bracket along the central axis of the slot. The additional moment created by a single force applied away from the centre of resistance, i.e. on the crown of the tooth, is not encountered in the present experiment since the brackets were bonded on the teeth passively with the aid of a stiff archwire. The moment of the couple of forces is unaffected by the location of the bracket on the tooth and is influenced only by the magnitude of the forces and the distance between them. The distance between them is influenced by the dimensions of the slot and the archwire as well as the shape of the archwire. The archwire type and dimensions remained stable throughout this experiment.

The magnitude of the couple of forces is influenced by the dimensions and material properties of the archwire and the bracket, the angle of twist of the archwire relative to the brackets, the mode of ligation, and the interbracket distance (Moran, 1987; Germane *et al.*, 1989; Morina *et al.*, 2008; Huang *et al.*, 2009; Archambault *et al.*, 2010). The decrease in the interbracket distance at the anterior region in lingual appliances increases only 1.5 times the relative stiffness of an archwire for third order bends and 3 times for first- and second-order bends (Moran, 1987). Slot orientation is an additional factor, which could influence relative torque expression between the anterior and posterior teeth in the Incognito brackets since the anterior brackets show a vertical slot with a vertical insertion direction, in contrast with the horizontal slot of the posterior attachments. The archwire thus runs like a ribbon. The present experiment investigated only the torque in the anterior teeth. The maximum moments created at the Incognito brackets were the highest between the four bracket systems, about 24% higher in comparison with these created at the conventional brackets. Higher moments were recorded in the STb brackets too (15 per cent), although not statistically different from the maximum moments created at the Incognito brackets. The moments at the In-Ovation L were about 19 per cent lower compared with these created at the conventional brackets.

The results of this study demonstrated a wide variation for maximum moments developed from lingual fixed appliances. As expected, the orientation of the bracket slot, i.e. vertical or horizontal, do not seem to influence this difference. On the contrary, the mode of ligation seems to affect the magnitude of maximum moment. Labial self-ligating brackets present higher torque loss compared with selective stainless steel brackets (Morina *et al.*, 2008). In a previous experimental comparison of the torque expression between conventional and active or passive self-ligating brackets systems, it was found that the active clip of the labial self-ligating bracket lowers the torque moment significantly below the effective moment (Huang *et al.*, 2009). In the present study, interbracket distance in the lingual bracket systems is influenced only by slot width since the models were identical. Slot width, measured by a fine tip digital calliper (150 mm ISO 9001 electronic caliper; Tesa Technology, Renens, Switzerland) is similar in Incognito and STb brackets but smaller in comparison with In-Ovation L brackets. Consequently, the recorded difference in moments could be attributed to the ligation mechanism or to the tolerance in slot size.

A similar bracket classification was obtained from the evaluation of the degrees of twist creating 5.0 Nmm of torque between the different systems. Although there is no scientific consensus regarding ideal torquing moment (Burstone, 1966; Bantleon and Droschl, 1988; Reitan, 1964), most of the authors agree that 5.0 Nmm is the minimum torque required for an upper central incisor (Gmyrek *et al.*, 2002; Harzer *et al.*, 2004; Huang *et al.*, 2009; Melenka *et al.*, 2011; Major *et al.*, 2011a, b). During the activation phase of the rotation cycle, the Incognito and the STb brackets reached this torque level earlier during the rotation cycle (at 9.4 and 11.0 degrees, respectively) in comparison with the conventional and self-ligating brackets. At the latter bracket system, the moment magnitude of

5.0 Nmm was recorded nearly at the end of the bracket rotation (at 13.9 degrees). The same trend was observed between the bracket types during the unloading phase of the rotation cycle, which represents the actual torque acting on a tooth during its movement, but the 5.0 Nmm was always recorded at a slightly higher rotational level within each bracket type. This means that the torque expression by decreasing angle is less than when the angle is increasing (Figure 2). This finding was confirmed in experiments with conventional brackets and with bracket rotation up to 63 degrees (Melenka *et al.*, 2011; Major *et al.*, 2011a). This was attributed to permanent plastic deformation mainly of the wire but also of the bracket. A less pronounced difference of the torque measured during loading and unloading was encountered in investigations using conventional (Meling *et al.*, 1997) or self-ligating (Major *et al.*, 2011b) brackets with lower rotational levels. Additional causative factors include friction and possibly binding between the wire and slot, bevelling of wire corners, and warping of the slot profile. Moreover, there is a lack of evidence on the stress relaxation in β-Ti wires.

Excessive torque play is not expected with a 0.0175 × 0.0175 inch archwire in 0.018 slotted brackets. For the same reason, the second part of the moment–angle curve, which includes the twist of the wire until it contacts the slot walls of the neighbouring brackets, is restricted too. At least in conventional labial brackets, the presence of elastic ligatures has a restraining effect that will lead to a small delivery of torque even though the play between wire and bracket has not been eliminated (Ødegaard *et al.*, 1994). In the present experiment, it was decided to use plastic modules since stainless steel ligatures do not exert homogeneous pressure, and as a result, the restraining effect on the wire would be unequal. After the contact of the wire with the slot walls of the neighbouring brackets, the slope (moment/torque rate) and the torque increase with the torsional stiffness (a steeper slope) of the engaged wires (Huang *et al.*, 2009). In the present simulation, the slope was calculated during the last linear part of the curves and was different between the bracket types. The highest slope was calculated in the Incognito, followed by the STb brackets, and the lowest slope in the self-ligating system. During the unloading phase, the slope was always lower within each bracket type. Archwires with increased cross section could be used in order to reduce the torque play and deliver better torque control. In this aspect, further investigation of lingual appliances should include the evaluation of customized 0.0182 × 0.0182 or 0.0182 × 0.025 inch TMA archwires, offered by the Incognito lingual system.

The findings of this *ex vivo* experiment should not be extrapolated in the clinical practice without scepticism. OMSS resembles closely the clinical situation of initial tooth movement within the periodontal space but it does not consider factors such as intra-oral ageing and saliva, which influence the forces and moments experienced by teeth over time. The actual force system acting on the teeth will probably vary, because of the presence of periodontal ligament, whose mechanical properties affect the transmission of the force system. Further investigation in this area should be conducted regarding tolerance in slot size in lingual brackets.

Conclusions

The Incognito and STb lingual brackets generated the highest moments. The lowest torque expression was observed at the self-ligating lingual brackets, followed by the conventional brackets.

The moment of the couple of forces created from a rectangular archwire in lingual bracket systems is influenced by the mode of ligation, i.e. conventional versus self-ligating, and not by the orientation of the bracket slot or the tolerance in slot size.

Torque expression during unloading, which represents the actual torque acting on a tooth during its movement, is less than during loading.

Acknowledgements

The authors of this article do not have a financial or beneficial interest in the companies that manufacture any of the products used in this study nor did they receive any funding to support this research activity.

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