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Torque expression of self-ligating brackets compared with conventional metallic, ceramic, and plastic brackets

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SUMMARY The purpose of this research was to investigate the torque capacity of active and passive self-ligating brackets compared with metallic, ceramic, and polycarbonate edgewise brackets. Six types of orthodontic brackets were included in the study: the self-ligating Speed and Damon2, the stainless steel (SS), Ultratrimm and Discovery, the ceramic bracket, Fascination 2, and the polycarbonate bracket, Brillant. All brackets had a 0.022-inch slot size and were torqued with 0.019 × 0.025-inch SS archwires. For this purpose, the labial crown torque of an upper central incisor was measured in a simulated intraoral clinical situation using the orthodontic measurement and simulation system (OMSS). A torque of 20 degrees was applied and the correction of the misalignement was simulated experimentally with the OMSS. Each bracket/wire combination was measured five times. Maximum torquing moments and torque loss were determined. The results were analysed with one-way analysis of variance, with the bracket serving as the sole discriminating variable, and the Tukey test at the 0.05 level of significance.

The ceramic bracket (Fascination 2) presented the highest torquing moment (35 Nmm) and, together with a SS bracket, the lowest torque loss (4.6 degrees). Self-ligating, polycarbonate, and selective metallic brackets demonstrated almost a 7-fold decreased moment developed during insertion of a 0.019 × 0.022-inch SS wire into a 0.022-inch slot and a 100 per cent increase in loss.

Introduction

In orthodontics, torque is employed to alter the inclination of all teeth, particularly the incisors. In general, the extent of change in the buccolingual inclination of the crowns depends on the wire torque stiffness, bracket design, the wire/slot play, and the mode of ligation. The wide array of combinations of altering factors in defining torquing moments make the empirical clinical determination of the appropriate torquing method a difficult task for the practising professional.

Rauch (1959) described torque as ‘a moment generated by the torsion of a rectangular wire in the bracket slot’. Depending on the amount of torsion, the size and quality of the wire, the play of the wire in the bracket slot, the angulation, and the deformability of the bracket, the archwire moves the root in a buccal or lingual direction due to the torsional load induced. The literature lists effective values for torquing moment in the range of 1.0–2.0 Ncm (Burstone, 1966; Bantleon and Droschl, 1988; Feldner *et al.*, 1994), whereas minimum values of 0.5 Ncm have been reported for torquing a maxillary central incisor (Morrow, 1978; Holt *et al.*, 1991).

Currently, there is a lack of evidence on the torque characteristics of various bracket–archwire combinations (Dobrin *et al.*, 1975; Germane *et al.*, 1989; Alkire *et al.*, 1997; Harzer *et al.*, 2004). This may be attributed to the complexity of the experimental configuration required in laboratory studies and the multiplicity of factors needed to be controlled in a clinical setting, including individual response to moments applied, variability in malocclusion, and the potential effect of other auxiliaries or treatment utilities affecting torque.

In the course of orthodontic tooth movement, the amount of activation, i.e. the elastic deformation of the torquing wire and consequently the force system, will vary significantly due to changes in bracket position (Drescher *et al.*, 1991; Bourauel *et al.*, 1992). Therefore, static determination of the torquing moment precludes a reliable estimation of bracket–archwire combinations, while a dynamic assessment is complex, requiring advanced experimental instrumentation.

Recently, the introduction of active and passive self-ligating brackets have presented a challenge to the profession because of the novel ligation mode and the potential alterations in the load and moment expression during mechanotherapy. Whereas some of these systems seem to present reduced friction *in vitro*, their torquing characteristics remain unknown. The latter may be lower relative to their standard edgewise counterparts, since torque requires the development of friction between the edges of the activated archwire and the bracket slot walls, to facilitate buccolingual inclination.

It was the aim of this study to experimentally investigate the torque characteristics of different brackets with respect to varying ligation mechanisms, design, and material composition.

Materials and methods

Six brands of orthodontic brackets were included in the study (Figure 1): the self-ligating Hanson Speed™ (Strite Industries, Cambridge, Ontario, Canada) and Damon™ 2 (Ormco, Glendora, California, USA), as well as the steel-brackets, Ultratrimm® and Discovery® (Dentaurum, Pforzheim, Germany), the ceramic bracket Fascination® 2 (Dentaurum), and the polycarbonate bracket Brillant® (Forestadent, Pforzheim, Germany). All brackets were of 0.022-inch slot size and were torqued with 0.019 × 0.025-inch stainless steel (SS) archwires (Dentaurum). The effect of the wires on the bonded buccolingual inclination of a maxillary central incisor was simulated using the orthodontic measurement and simulation system (OMSS). The major components of the OMSS are two force–moment sensors capable of measuring forces and moments simultaneously in all three planes of space (Figure 2). The two sensors are mounted on motor-driven positioning tables with full three-dimensional mobility, whereas all mechanical components are built in a temperature-controlled chamber, interfaced with a computer. This system is capable of performing various types of measurement, and the resultant force-deflection curves are recorded, thus facilitating a means to study the loads arising from a mock orthodontic tooth movement (Bourauel *et al.*, 1992).

Torquing moments were studied on an aligned and levelled maxillary arch of a Frasaco model (Franz Sachs, Tettnang, Germany) attached to the OMSS (Figure 3). The teeth of the model had been set-up in a wax bed and levelled carefully prior to experimentation. The brackets were bonded on the crowns of the maxillary teeth of the model and the archwire was ligated with a SS ligature (in the conventional edgewise brackets) or the clips had been closed. All measurements were performed by one investigator (EM), who closed the SS ligatures in a standardized way. The ligature wires were tightened and

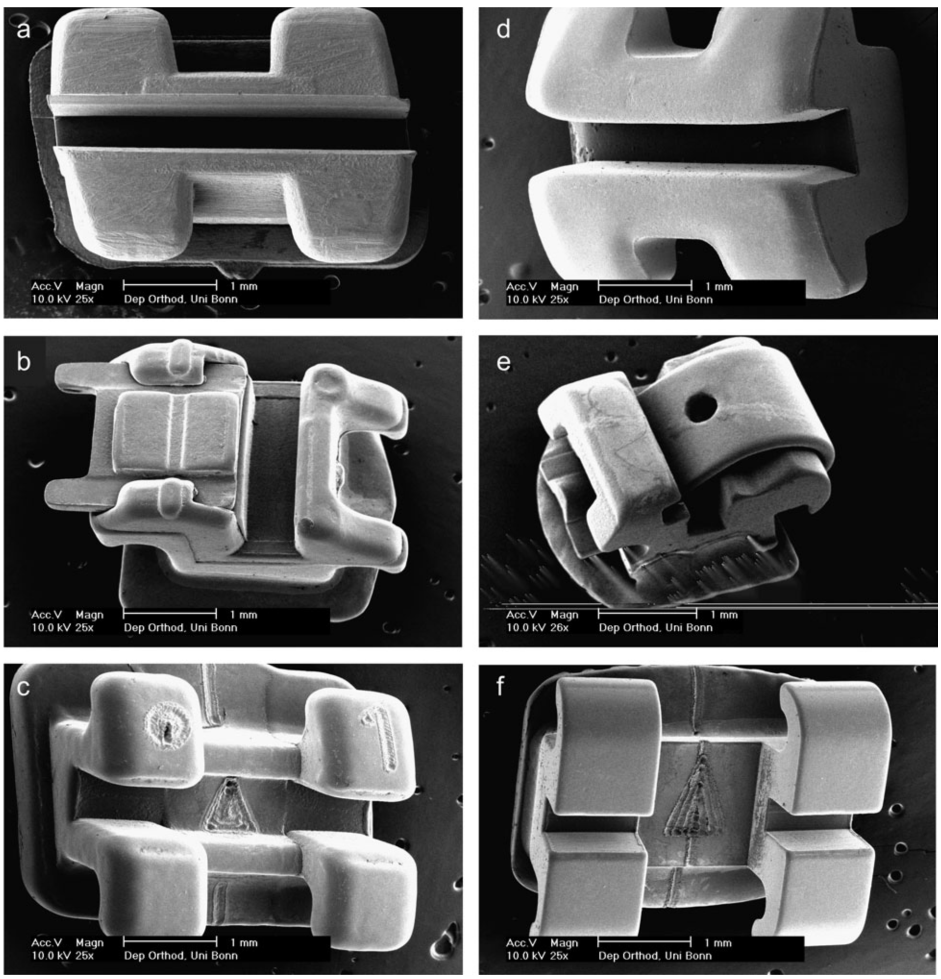

Figure 1 Scanning electron micrographs of the bracket types investigated in this study (a, Brillant; b, Damon 2; c, Discovery; d, Fascination 2; e, Speed; and f, Ultratrimm).

adjusted thus that the wire was securely pressed onto the slot bottom and no play was obvious. The bracket to be tested was attached to the force–moment sensor of the OMSS via an adaptor (Figure 3). A labial crown torque of 20 degrees was applied to the bracket as measured by the OMSS sensor, and the projected spatial crown orientation in the buccolingual direction was calculated by the OMSS using a mathematical model integrated in the software of the OMSS and then executed by means of the stepper-driven positioning tables. In general, the system comprises three forces and three moments. The sensors of the OMSS register these six components independently. The reactive moments at the centre of resistance, resulting from the leverage effect of the force application on the bracket, are also calculated by the control programme of the OMSS and entered into the simulated tooth movement. For this purpose, the distance between the point of force application in the bracket slot and the centre of resistance of the tooth at the level of the first root third was set at 10 mm. In the simulation employed in this study, each tooth movement was subdivided into 1000 increments, with a torquing moment threshold of 0.2 Nmm. Five measurements were performed for each bracket–archwire combination.

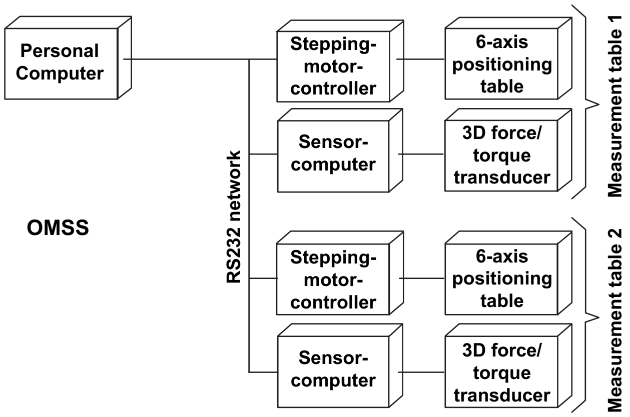

Figure 2 Schematic diagram of the orthodontic measurement and simulation system (OMSS).

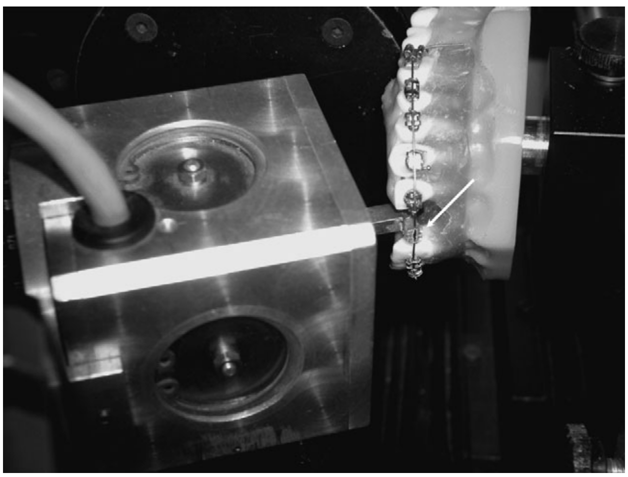

Figure 3 A Frasaco model mounted in the orthodontic measurement and simulation system (OMSS). The torque was measured on maxillary incisor brackets (arrow) attached to the sensor of the OMSS.

Torquing moment (Nmm) and torque loss (degrees) data were analysed with one-way analysis of variance with the bracket type serving as a sole discriminating variable, and the Tukey test at the 0.05 level of significance.

Results

Table 1 shows the maximum torquing moment registered for the brackets in combination with a 0.019 × 0.025-inch SS archwire. With the exception of the ceramic brackets, which indicated the highest moment, all other appliance systems presented an almost 3-fold reduction in the moment developed upon insertion of the archwire.

The torque loss of brackets is shown in Table 1. The ceramic bracket demonstrated the least loss, in accordance with the maximum moment data, along with the SS appliance.

Figure 4 shows the course of the moments in the simulated tooth movements. The slopes of the fitted straight lines give

Table 1 Maximum torquing moment (Nmm) and torque loss (°) of the brackets included in the study (0.022-inch slot with 0.019 × 0.025-inch stainless steel archwire).

Bracket	Torquing moment (Nmm)*			Torque Loss (°)*		
	Mean	Median	SD	Mean	Median	SD
Brillant®	13.5 (A)	12.6	2.9	11.5 (A)	11.6	1.9
Damon™ 2	7.8 (A)	7.6	4.0	11.1 (A)	10.0	2.9
Discovery®	7.5 (A)	7.6	3.3	11.1 (A)	10.0	2.9
Fascination® 2	35.6 (B)	35.8	2.8	4.7 (B)	4.8	1.6
Speed™	8.0 (A)	8.4	3.7	10.9 (A)	11.0	2.1
Ultrarimm®	12.3 (A)	10.7	5.5	6.6 (B)	8.0	4.7

*Means with same letter are not significantly different at the 0.05 level.
SD, standard deviation.

the values of the moment/torque rate of the respective material combination and Figure 5 demonstrates the variation of moment to torque rate for the brackets tested. The Fascination 2 brackets exhibited the highest moment/torque rate at 2.0 Nmm/degree followed by the Brilliant brackets at 1.2 Nmm/degree; all other brackets developed slopes on an identical level of 0.4 Nmm/degree.

Discussion

The results of this study suggest that self-ligating brackets present reduced torquing moments compared with conventional ceramic brackets, and higher torque loss compared with ceramic and selective SS brackets. In general, for a given combination of archwire and bracket slot size, the effective torque applied to the tooth crown depends on the modulus of bracket slot walls and the torsional stiffness of the archwire, the morphology of the edges of these components, and the ligation method. Compliant and soft materials are plastically deformed during torque application (Harzer *et al.*, 2004), thus absorbing a significant portion of the energy given through the insertion of archwires into the slot. Moreover, slot and wire edges, which have been rounded, deviate from those with a rectangular shape (Cash *et al.*, 2004) or specified dimensions (larger for slots and smaller for wires) contribute to increased play, thereby reducing the torque expression capacity of the biomechanical configuration used. Measured actual slot sizes of the investigated brackets using thickness gauges varied significantly from 0.54 mm (Speed) to 0.59 mm (Damon, nominal slot size in the 0.022-inchsystem: 0.56 mm), while the archwire used had a homogeneous vertical dimension of 0.48 mm (nominal wire size of a 0.019 × 0.025-inch wire: 0.48 mm), resulting in increased play for certain brackets. Consequently, care must be taken to use an appropriate wire/bracket slot combination to avoid too much play with smaller wire sizes in oversized slots.

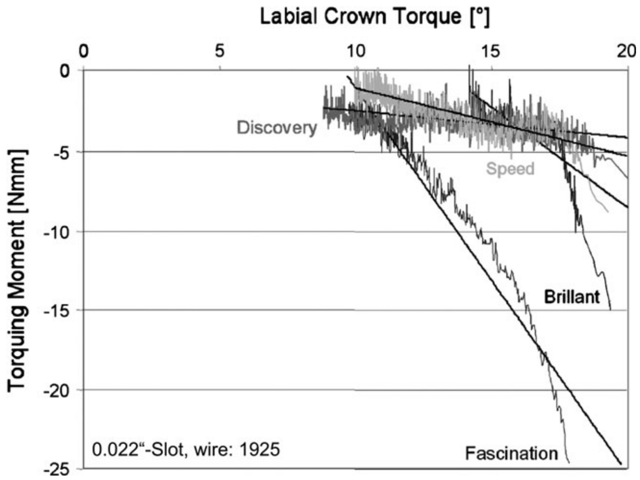

Figure 4 Moment–torque deactivation curves of selected bracket types. Straight lines have been fitted to the moment curves in order to determine moment–torque rates.

The torsional stiffness of archwires may be a significant contributing factor for this phenomenon. This arises from the underestimation of stiffness relative to the size of the archwire and the overall increased emphasis placed on the concept of variable modulus orthodontics, which aim at early filling of the slot followed by increasing the modulus of the wires. However, reduced modulus alloys such as NiTi and β-Ti (TMA) present only a fraction of the torsional stiffness of SS, and, along with their reduced hardness, are ineffective in transmitting torque moments to bracket slots. This effect was demonstrated by Kusy (1983) with the use of relative torsional stiffness indices for various archwire alloys and the utilization of nomograms to depict the values of different composition/

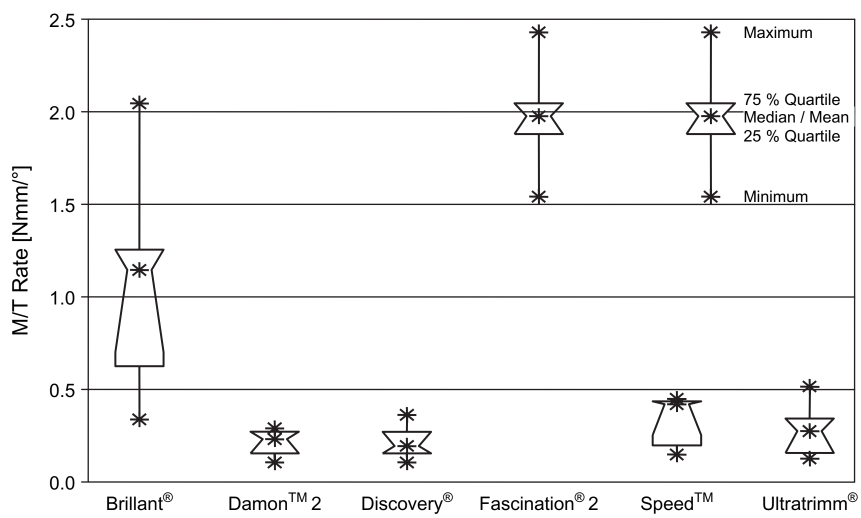

Figure 5 Box–whisker plots of the moment–torque rates of the different brackets.

size combinations. Thus, it was shown that a 0.017 × 0.025-inch NiTi archwire possesses a torsional stiffness of 1.7, an almost 7-fold decrease in stiffness, relative to a SS archwire of the same size.

The results of this study are not in agreement with a recent clinical investigation, which examined maxillary central incisor inclination with conventional and Damon brackets, and reported that there was no significant difference between the torque of incisors between the two appliances (Pandis *et al.*, 2006). However, the mechanotherapy used in that investigation greatly influenced the torque expression of the appliances since the use of rectangular NiTi reverse curve of Spee archwires, which are torqued more than 20 degrees, may cancel out any appliance variability in expressing torque. Because of the limitations of the experimental apparatus used in the present study, the torque transmission was confined to the insertion of a 0.019 × 0.025-inch wire into the slot. Whereas the use of NiTi has been found to counteract the loss of torque shown in this investigation in the case of Damon brackets, no extrapolation could be made for the plastic appliances tested because of additional factors pertinent to the low hardness and low modulus of these appliances (Eliades *et al.*, 2004; Gioka and Eliades, 2004).

An additional factor in the clinical routine application of torquing moments relates to the interbracket distance defined by the crown and bracket widths (Jarabak and Fizzel, 1972). Also, the vertical positioning of the brackets on the tooth plays an important role, since a vertical shift of 3 mm can change the torque angle by around 15 degrees (Meyer and Nelson, 1987), although Miethke (1997) proposed that a torque variation of 10–15 degrees may arise from a vertical inaccurate placement of 1 mm. The morphology of the teeth can vary greatly and that affects the clinical use of a torque (Morrow, 1978). The angle between the longitudinal axis of the root and the crown at an upper central incisor can also vary (Carlsson and Rönnermann, 1973), modifying the outcome of application of the same moment on different shaped crowns.

The results of this study demonstrated a wide variation for maximum moments developed during insertion of the archwire into the bracket slot, which ranged from 4 to over 35 Nmm. The Fascination 2 bracket, which showed the highest value, possesses the highest raw material modulus of elasticity and increased roughness of the slot walls arising from the manufacturing process. This may also contribute to increased wire–slot friction, decreasing the clearance of the wire into the bracket. On the other hand, the increased stiffness of the ceramic brackets predisposes to brittle fracture, a fact, which was noted during testing with fractured bracket wings being more frequent in this bracket group (Holt *et al.*, 1991; Eliades, 2007).

In addition, a 100 per cent difference was noted between the torque loss of two groups of brackets which involved the high-loss self-ligating plastic and selective metallic appliances and the low-loss ceramic and metallic bracket, reflecting the difference both design and manufacturing process. Such an extended torque loss, as shown in this study, for various brackets, may have potential clinical implications in the axial inclination of maxillary anterior teeth, which, if unnoticed, can complicate treatment. This derives from the fact that a 10 degree loss may cancel out the torque prescribed into the bracket for some prescriptions such as the Roth which is within the same order of magnitude with that of the loss. Therefore, the mechanotherapy in this case must incorporate reversed curve of Spee wires, which are significantly pre-torqued, provided that intrusion of the anterior maxillary teeth is desirable, or torque in the wire, or a high torque prescription.

Conclusions

The ceramic bracket (Fascination 2) presented the highest torquing moment (35 Nmm) and along with a metallic bracket the lowest torque loss (4.6 degree); self-ligating, polycarbonate, and selective metallic brackets demonstrated almost a sevenfold decreased moment developed during insertion of a 0.019 × 0.022-inch SS wire into a 0.022-inch slot and 100 per cent increased torque loss relative to the ceramic bracket.

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