Original Article

Moments Generated during Simulated Rotational Correction with Self-Ligating and Conventional Brackets

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ABSTRACT

Objective: To assess comparatively the magnitude of moments generated during rotational correction from different bracket systems during the late leveling and alignment stage of orthodontic treatment.

Materials and Methods: The three types of brackets assessed were Orthos2 (ORMCO, Glendora, CA), Damon2 (ORMCO), and In Ovation-R (GAC, Bohemia, NY). The brackets were bonded on replicas made of resin from models constructed from an aligned patient's mandibular arch, and a 0.014- $\times$ 0.025-inch CuNiTi (ORMCO) wire was inserted. Orthodontic rotational correction was simulated on the Orthodontic Measurement and Simulation System from $-5°$ to $+5°$ rotation in 0.25° increments on the distal and mesial direction. The moments generated at each increment of rotation throughout the full rotation path were statistically analyzed using a two-way analysis of variance and Tukey test at the .05 level of significance.

Results: Both bracket type and direction of rotation showed an effect on moment magnitude. The highest moment (27.2 Nmm) was observed for the Damon2 bracket assigned to its noncompliant slot wall door. Higher moments were found during distal premolar rotation. The In Ovation-R showed a magnitude of moment in the range of 9.0 Nmm in the same direction, whereas conventional brackets presented the lowest moments (5.0 Nmm).

Conclusions: A wide variation in magnitude of moments exerted by self-ligating and conventional brackets is noted in the simulated rotational correction of teeth, which relates to the geometry of the dental arch, the tooth position, and the rigidity of the closing component of the bracket slot.

KEY WORDS: Self-ligating brackets; Rotational displacement; Moments

INTRODUCTION

The incorporation of self-ligating brackets is sought to replace the existing ligation methods with elastomeric and stainless steel ligatures to improve clinical efficacy.[1–3] Consistent archwire engagement throughout orthodontic treatment and elimination of the need for frequent visits for the replacement of ligatures were the main advantages listed for the new ligation mode.[4,5] In addition, it has been proposed that because of bracket-wire relations, the use of light forces and reduced friction orthodontic tooth movement is facilitated.

Correction of the axial variation of teeth requires a moment applied to the bracket to form a rotational movement. Therefore, bracket width may affect moment development during axial rotations since the moment of the rotational couple is equal to the applied ligation force multiplied by the effective attachment width; thus, wider appliances, in general, produce higher moments.[6,7] There are a number of factors, such as archwire dimension, degree of crowding, relaxation of ligatures, clip modulus of elasticity, and relaxation of self-ligating bracket engaging mechanism, that may alter or modify the load transmitted to teeth.[8] A notable scarcity of evidence exists on the forces generated during the activation of an archwire in self-ligating brackets, whereas no information is available on the development of moments during rotational movement.

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The magnitude of force developed during engagement may also vary depending on the number of teeth ligated in the proximal and distal segments of the arch. This effect arises from the increased stiffness of the wire-bracket complex associated with the presence of many dental units incorporated into the mechanotherapy.[9]

The purpose of this study is to investigate comparatively the forces and moments produced during the leveling and aligning stage of orthodontic tooth movement from different bracket systems.

MATERIALS AND METHODS

Resin replicas (Palavit G, Heraeus Kulzer GmbH, Hanau, Germany) were constructed from the original mandibular model of a patient under treatment, who was at the aligned midtreatment stage and was about to receive a 0.014- $\times$ 0.025-inch NiTi archwire. The following three bracket systems were used: a conventional Orthos2 (ORMCO, Glendora, CA), a passive self-ligating Damon2 (ORMCO), and an active self-ligating In Ovation-R bracket (GAC, Bohemia, NY), all with a 0.022-inch slot and the same prescription. The left first premolar was removed from the resin model to allow for application of a sensor. Brackets were bonded from a second premolar to a second premolar.

A 0.014- $\times$ 0.025-inch CuNiTi Damon arch form wire (ORMCO) was inserted into the brackets to the constructed model, and the latter was mounted sequentially on the Orthodontic Measurement and Simulation System (OMSS) table while the corresponding bracket of the removed premolar was mounted on a special base that was fitted on the OMSS sensor. The major components of the OMSS system consist of two force-moment sensors capable of measuring forces and moments in all three planes of space simultaneously.[10] 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 and 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.

Once the constructed model was mounted on the OMSS table and the corresponding bracket was mounted on the OMSS sensor, the model and the bracket were positioned in such a way that they duplicated the arch form of the original aligned dental arch. The appropriate calibrations and adjustments were performed on the OMSS computer program to bring the forces on the censor/bracket to zero. A simulated rotational movement around the long axis of the tooth was applied, ranging from $-5°$ (distal rotation) to $+5°$ (mesial rotation) at 0.25° increments. Figure 1 shows the resin model mounted on the OMSS and the corresponding bracket in a $-5°$ rotation situation.

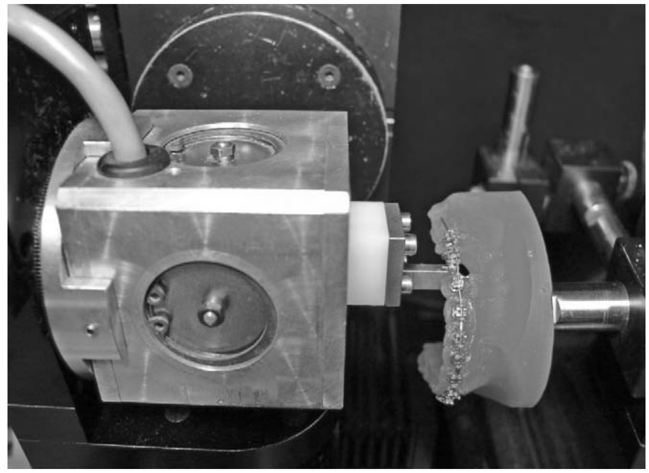

Figure 1. The resin model mounted on the Orthodontic Measurement and Simulation System and the corresponding bracket in a $-5°$ rotation situation.

Each of the bracket-archwire simulations was performed five times at the entire range of movement, with a newly inserted wire. The values of moments generated from the simulated movements were measured, recorded, and saved in the computer using the OMSS proprietary software.

The absolute values (irrespective of the sign denoting the direction of rotation) of the moments generated from the rotational simulation were analyzed with a two-way analysis of variance (ANOVA) procedure with the moments serving as the dependent variable, while the bracket and direction of rotation (mesial-distal) were set as the predictor variables. Group differences were further investigated with the Tukey post hoc test and with a family error rate set at .05.

RESULTS

The ANOVA showed that the variable direction presented a significant effect on the variation of moment in the rotational model. This is illustrated in Figure 2, in which the moment level per increment of rotation throughout the total path (mesial-distal rotation) indicates a large variation in moment (and force) for both self-ligating brackets.

The Damon2 bracket presented a much higher moment relative to the In Ovation-R and conventional appliances in the distal direction ($-5°$) (Table 1). Although reversing the direction of rotation produced no difference between the self-ligating brackets, the conventional appliance still generated 50% less moment

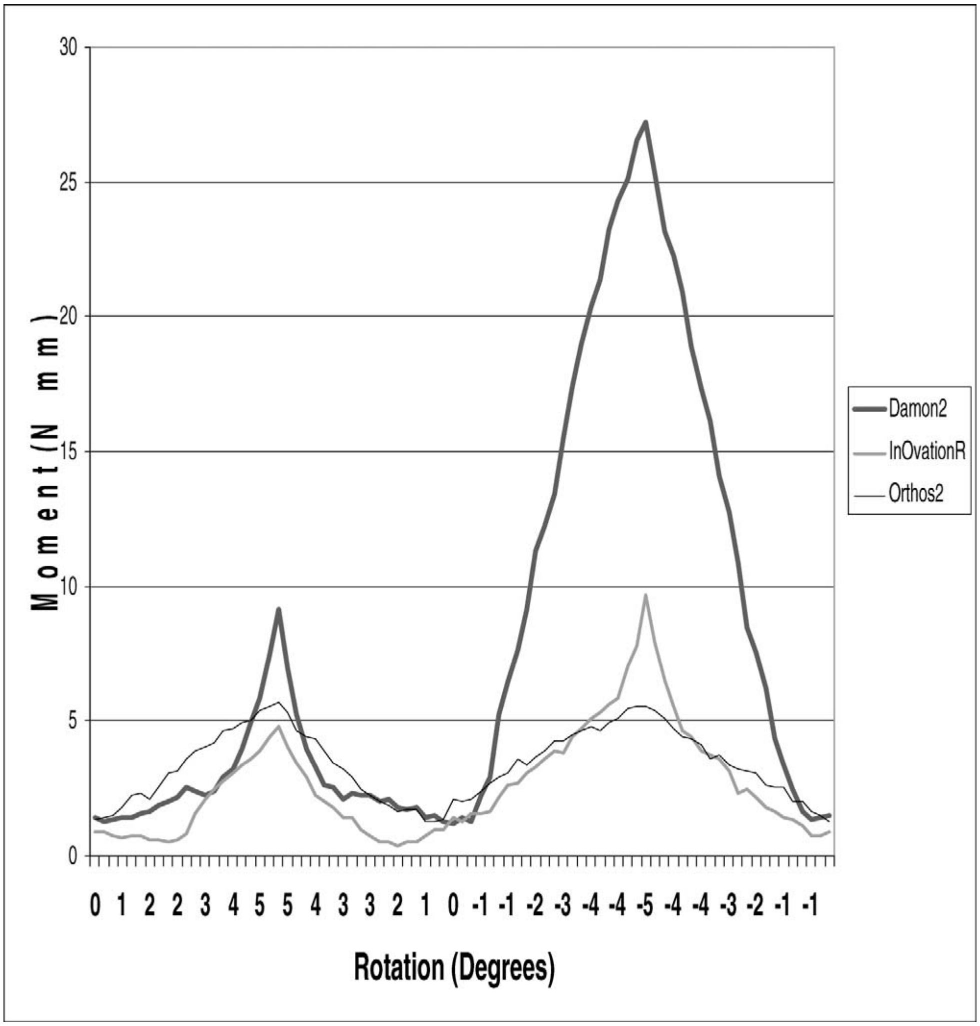

Figure 2. Variation of magnitude of force per rotation increment for the brackets included in the study. Note that higher moments are associated with a specific direction of rotation, which coincides with distal rotation, toward the arch segment where fewer teeth are engaged (denoted by negative values). For both directions, the Damon2 bracket showed higher moments relative to the conventional one.

Table 1. Maximum Values of Moments Corresponding to Maximum Rotation (−5° and 5°) of Brackets Included in the Study[a]

Bracket-Direction Group	Moment, Nmm		Tukey Grouping[b]
	Mean	SD	
Damon2 B	27.2	3.4	A
In-Ovation-R B	9.63	1.8	B
Damon2 A	9.14	2.98	B
Orthos2 A	5.7	1.7	C
Orthos2 B	5.52	1.16	C
In Ovation-R A	4.79	0.6	C

[a] Direction A denotes a mesial rotation for a premolar (toward the arch segment with more teeth engaged into the wire segment). Direction B denotes a distal rotation for a premolar (opposite to the arch segment with more teeth engaged in the archwire).

[b] Means with the same letter are not significantly different at the .05 level of significance.

(and force) at this mode relative to its self-ligating counterparts.

Figures 3a–c outline the bracket-wire configurations and present an explanatory model for the results of the present study. Figure 3a represents the passive configuration in which the wire is seated at the bottom of the slot with zero moments generated, whereas Figure 3b depicts distal (−5°) and Figure 3c mesial (+5°) premolar rotation.

DISCUSSION

Self-ligating brackets have been advocated for the light forces, which are attributed to the increased archwire-slot clearance arising from the lack of contact points of ligature and wire. The present study indicates that the design of the closing mechanism incorporated in active or passive self-ligating brackets and its vari-

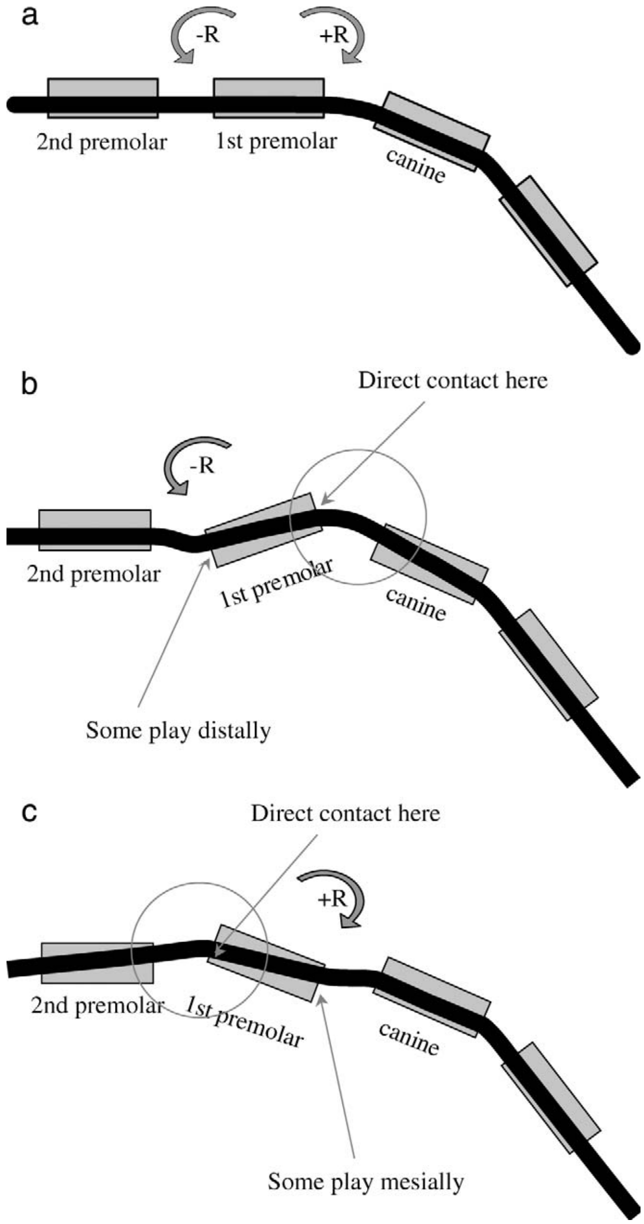

Figure 3. (a) Passive configuration in which the wire is seated at the bottom of the slot with no moments generated. (b) Distal premolar rotation of $-5°$. (c) Mesial premolar rotation of $+5°$.

able stiffness or rigidity may differentiate the magnitude of moments exerted by an activated archwire.

The model used in this study simulates the movement of teeth in a leveled and aligned arch, accompanying the insertion of a rectangular NiTi archwire. The choice of the specific size and alloy of the archwire inserted simulates the mechanotherapy employed by the Damon bracket system manual.[11] Although conventional and active self-ligating brackets do not employ similar mechanotherapeutical guidelines, the 0.014- $\times$ 0.25-inch NiTi archwire in an 0.022-inch slot represents a feasible alternative of standard wire sequencing. In addition, the specific range of displacement used in the experiment was confined to 5° in the mesial and 5° in the distal direction because at the time of wire insertion, it is expected that initial leveling and aligning would have probably eliminated variation in crown spatial orientation relative to the arch form.

The highest value obtained from Damon2 brackets is more than 100% greater relative to its counterparts in this study, whereas it is more than double the values reported for derotation of canines of 140°.[12]

The results of this investigation indicate that the direction of the premolar rotation (distal or mesial), which was used as a model, exerts a significant effect on the magnitude of the generated moments. This may be assigned to the number of teeth incorporated in the mechanotherapy mesially or distally to the arch location where the sensor was inserted.[13] Therefore, the lower values reported in this study for favorable direction of rotation may not be clinically relevant for different teeth (ie, an incisor for which an equally large number of adjacent teeth are engaged into the wire).

During distal rotation in the active self-ligating bracket, the anterior edge of the bottom of the slot pushes on the wire and deforms it when it encounters the clip of the canine bracket. At the same time, a large amount of wire has to be pulled through a large number of bracket slots. The distal part of the first premolar wire bears some play compared with the mesial section, and it pulls through only one bracket slot, that of the second premolar, yielding lower moments. The resulting high wire deformation anteriorly due to the geometry and the fact that the wire must be pulled through multiple bracket slots generates higher moments during the distal premolar rotation compared with the mesial premolar rotation.

In the mesial rotation configuration, the posterior edge of the bottom of the slot starts pushing immediately on the wire as the slot bottom is in contact with the wire. The lower moments generated during the mesial premolar rotation are due to the arch form geometry and the fact that the wire is pulled through only the bracket slot of the second premolar. In addition, the initial play on the mesial section of the bracket-wire system results in relatively small wire deformations and consequently lower moments.

The increased moment magnitude found for the Damon2 bracket could be attributed to the rigidity of the closing component of the slot, which limits the available space for the wire to move and dissipate some of the energy given at engagement. Although this slot wall allows for increased play when small diameter wires are inserted into the slot, its rigidity and lack of deformable unit results in higher loads developed during rectangular wire engagement. This is in contrast with the case of In Ovation-R bracket, which features an elastically deformed clip, which is compliant allowing more outward movement of the wire from the bottom of the slot. The same occurs with conventional brackets owing to the deformation of the elastomeric ligatures, which long term probably relax more than the clip of the In Ovation-R bracket. The foregoing notion might explain the independence of the magnitude of the generated moments with the direction of rotation for the conventional bracket.

Although this study examined the maximum magnitude of moments developed during the applied rotation of 5°, no information can be revealed for the efficacy of bracket to apply a steady derotational moment. This concern is particularly relevant to elastomeric modules since these polyurethane-based elastomers have been found to lose approximately 50% of the force applied within the first 24 hours in an in vitro setup.[14] More decay is expected in the oral environment because of the severity of conditions existing in the presence of pH fluctuations, temperature variations, enzyme action, and mechanical loading. Thus, their use as a ligating medium in rotational movement has been questioned, and stainless-steel ligatures have been suggested for more efficient and consistent engagement.[15] The use of the latter nonetheless is associated with the development of higher moments, which may exceed the biological range.[16]

The In Ovation-R bracket presented higher values in the distal rotation compared with the conventional one; however, this difference was eliminated when the direction was set to that of more teeth engaged or a smaller interbracket distance. This behavior may be attributed to the limits of clip displacement, as determined by the outer bracket wing borders and the properties of the clip. The clip responds immediately at low loads showing a compliant character, but when the deformation of the closing mechanism exceeds a certain value, it becomes stiffer to avoid buccal movement of the archwire.

Potential differences in the values reported in this study and previous investigations examining self-ligating brackets should be assigned to different types of closing mechanisms noted among self-ligating appliances. Moreover, the configuration of the present experimental setup involved the study of moments in a mandibular arch of 10 teeth in contrast to the engagement of a single tooth[16] in a similar approach, a fact that may greatly differentiate the moments developed.

CONCLUSIONS

- A higher magnitude of moments developed in the opposite direction of the higher number of teeth engaged into the archwire.
- Higher moments were associated with the passive self-ligating Damon2 bracket.
- Conventional brackets showed the lowest moment magnitude developed irrespective of direction.

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