Original article

A comparative experimental investigation of torque capabilities induced by conventional and active, passive self-ligating brackets

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Summary

Introduction: A proper selected bracket-archwire combination displays a determining factor in the efficacy of torque applied to a tooth at the final stages of an orthodontic treatment. The objective of the current study was to assess the torque capabilities of various bracket systems combined with diverse archwire materials and cross-sections.

Methods: The study comprised of four different 0.018-inch slot orthodontic brackets: the passive and the active self-ligating 1. Swiss Nonligating Bracket (SNB) and 2. SPEED and the metallic and the plastic conventional ligating 3. Mini Mono and 4. Brilliant, respectively, and four different archwire types: stainless steel and Nitinol: 0.016 × 0.016 inch and 0.016 × 0.022 inch. A 20 degrees labial crown torque (+20 degrees) and then a 20 degrees palatal crown torque (−20 degrees) were applied gradually on the upper right central incisor. Maximum torquing moments and torque play were registered.

Results: Highest torquing moments were expressed by combining SPEED® with 0.016 × 0.022 inch stainless steel archwire. Lowest moments, but highest torque loss were registered by inserting a 0.016 × 0.016 inch Nitinol archwire in conventional ligating brackets.

Conclusions: Active self-ligating system manifests the best torque effectiveness. An evident dependence of the torque expression is displayed both on the type of ligation and on the material of the archwire.

Introduction and literature review

In clinical orthodontics, optimal labiolingual inclination of both posterior and anterior teeth is considered essential to establish an esthetic smile line, a proper occlusal relationship, and subsequently long-lasting stability of the orthodontic outcome. In contemporary fixed appliances the labiolingual inclination can be determined through a moment generated by the torsion of a rectangular wire in the bracket slot (1). Inadequately, inclined incisors result in a dental arch constriction, as it has been evaluated that for every 5 degrees fallacy of anterior inclination a decrease of about 1 mm of the dental arch is to be expected (2).

Andrews has firstly introduced the prescription of brackets, underlying the necessity of including the three-dimensional control of individual teeth in the bracket design (3). Over the years, a plethora of experimental and clinical studies have been conducted in an attempt to specify the optimal grade of inclination of the upper incisors in course of an effective orthodontic treatment (3–8). Nevertheless, a striking diversity remains still among various bracket prescriptions and clinically estimated anterior dentition torque magnitudes. In particular, the torsional clinical outcome may deviate up to 100 per cent from the prescriptive values (9). The provided lack of uniformity mirrors the lack of clinical evidence in this field, and
may lead to a scarcity of consensus referring to the definition of the optimal torsional moment for an efficient treatment outcome. The individual preferences in tooth position or treatment philosophy can be factors implicated in this diversity of clinical results (10).

In clinical conditions there is a fraction of the torque that is built into the bracket, which remains unexpressed, giving rise to slot-wire play or third-order clearance. In this concept, a number of reports available in the literature have illustrated the pivotal role of the play between the adjacent bracket and wire on the explanation of the controversy of the results between theoretical and evaluated torque moments. (11–15).

Kusy introduced the use of nomograms in order to depict the material stiffness of the archwire, determined with the aid of relative bending and torsional stiffness indices for various bracket-archwire combinations (16). Advances in metal manufacturing technology introduced variable-modulus orthodontics, which take advantage of different alloys in archwire selection while maintaining the same or similar cross-sections. The major benefit of this treatment approach is that before selecting the wire, the clinician can determine the amount of play that is required according to the desired movement type or treatment stage and irrespective of the material stiffness of the archwire (17).

The 0.018-inch bracket system was developed as an adaptation to the higher stiffness of stainless steel that would allow the material to be used for optimised torqueing control. Heavier archwires in a larger slot are too stiff for any application besides stabilization (18). A disadvantage of the 0.018-inch slot is that in many instances insufficient play between the wire and the bracket is present in applications where a heavier wire is needed (19). Nonetheless, precise delivery of torsional moment in the oral cavity is rather difficult, because the working range in torsion of stainless steel wires is somewhat limited (20).

According to Harradine, the concept of self-ligation is as old as the edgewise brackets (21). However, in the past two decades there has been resurgence in the manufacturing and release of self-ligating appliances. Recently, the introduction of active and passive self-ligating brackets has presented a challenge to the clinical orthodontics because of the novel ligation mode and the potential alterations in load and moment expression during mechanotherapy. The scientific evidence in this field has become stronger in recent years, although not in an analogous way to the demand for these appliances. Considerable research has been conducted evaluating the torqueing efficiency of various archwires into conventional and self-ligating brackets (22–33).

Therefore, the main objective of the current study was to comprehensively investigate the torque efficiency of various archwires combined with diverse bracket systems used in clinical orthodontics. Furthermore, the provided experimental study aimed to the clarification of the parameters affecting the efficacy of the bracket-wire complex in facilitating the desirable buccolingual inclination of the tooth.

**Material and methods**

**Study materials**

The current experimental investigation includes two types of orthodontic brackets: 1. self-ligating brackets (Swiss Nonligating Bracket, a newly introduced passive self-ligating bracket, Tröster Applications, Magden, Switzerland; and SPEED, an active self-ligating bracket, Strite Industries, Ontario, Canada), and 2. conventional ligating brackets (Mini Mono and Brilliant, Forestadent, Pforzheim, Germany). All brackets had a nominal 0.018 inch slot size. Each of these brackets was combined with four different archwires: 1. 0.016 × 0.016 inch stainless steel, 2. 0.016 × 0.022 inch stainless steel, 3. 0.016 × 0.016 inch nickel-titanium (NiTi), and 4. 0.016 × 0.022 inch NiTi. The archwires were ligated into the slot of conventional brackets with elastomeric modules of an outer diameter of 0.012 inch (molded O, ORMCO). All material combinations used in terms of the study are provided in Table 1.

**Simulated torque build-up**

A Frasaco model of a levelled and aligned maxillary arch has been used for the construction of four resin replicas (Palavit G, Heraeus Kulzer GmbH, Hanau, Germany). An ideal stainless steel archwire of 0.018 × 0.025 inch was used to passively bond the brackets up to the second premolars onto the models with an acrylic adhesive. Additionally, this ideal archwire was used for the initial calibration of the system. At that time all forces/moments were nullified. From each one of the acrylic models the right central incisor was removed to allow for placement of a sensor, as all the measurements were conducted exclusively on that tooth. The standardization of the bonding process of the right central incisor bracket to a bracket holder was succeeded through a jig.

**Experimental device**

The orthodontic measurement and simulation system (OMSS) was used for the in vitro evaluation of the torque capabilities of the investigated brackets. The OMSS is based on the principle of the two-tooth model introduced by Burstone and allows the measurement of forces and moments in all three planes of space acting on two regions simultaneously (34–36). For this purpose, the OMSS has two stepping motor-driven positioning tables equipped with force/moment transducers monitored by a personal computer, which controls the measurements. The whole mechanical assembly of the OMSS is built in a temperature-controlled chamber (VEM 03/400, Vötsch Heraeus, Hanau, Germany), which is essential especially when investigating temperature-dependent alloys, i.e. NiTi.

**Experimental configuration**

In terms of the current experimental set-up was used only the left positioning table. The acrylic model was mounted on the OMSS table and the bracket holder with its adjacent bracket of the right central incisor was fixed to the corresponding force sensor of the experimental device. The whole assembly now simulates an original aligned dental arch. All measurements were performed by one investigator, who ligated the archwires in a standardized way. The elastomeric ligatures were positioned with a needle holder. A three-minutes waiting period was allocated in order to allow a reproducible amount of stress relaxation to occur (37).

A rotation of the bracket along the central axis of the slot up to 20 degrees buccally (+20 degrees) (Figure 1) and afterwards palatally (−20 degrees) was generated in the torque simulation by the OMSS. These movements were accomplished in increments of 0.25 degrees. After each rotational cycle, the bracket returned to its initial position. The projected spatial crown inclination in the buccolingual direction was calculated by the OMSS sensor through a mathematical model integrated in the software of the experimental device. The moments were recorded at both loading and unloading positions. Each of the bracket-archwire simulation was performed five times at the entire range of movement. A new archwire was inserted after the completion of every second measurement, in an attempt to eliminate the plastic deformation of the stainless steel archwire. Moreover, in
order to include the calculation of the reactive moments at the centre of resistance resulting from the leverage effect of the force application on the bracket, the centre of resistance was positioned at 10 mm apically and 4.5 mm lingually to the point of the torque application. In the simulation employed in this study, the measuring range of the torquing moments was ±450 Nmm with a torquing moment threshold of 0.2 Nmm. During investigating NiTi archwires the temperature was stabilized at 37(±1)°C, which corresponds to the intra-oral temperature (38).

Each experiment was completed after about 80 measurement cycles. In each of these measurement cycles, the moments generated after the application of a rotation movement of 20 degrees along the central axis of the tooth have been recorded and subsequently presented as a curve. Through these curves, apart from the moments, the torque play of each wire engaged in the corresponding bracket slot was estimated, too. In particular, the slope of the first fitted straight line at the beginning of the orthodontic simulation defines the estimated torque loss of the respective material combination.

Statistical analysis
The mean values of the five repeated measurements in every specimen of the generated torquing moments (Nmm) and torque loss (degrees) were calculated at the maximum rotation for +20 degrees and -20 degrees and were subsequently statistically analyzed with two-way analysis of variance (ANOVA) (Table 2 and 3). Group differences and the normal distribution of the data were specified through the Tukey post hoc comparisons test with the family error rate set at 0.05 (Table 4 and 5). All statistical analyses were performed with the SPSS software version 20.0 for Windows (SPSS Inc., Chicago, Illinois, USA).

Results
Table 2 is presenting the maximum torquing moments registered for each bracket design combined with the various archwires used in course of the current experimental investigation. The moments generated through the rotational movement of a maxillary central incisor range from 9.4 N (referring to Mini Mono) up to 35.4 N (referring to SPEED). The greatest moment was expressed through the combination of SPEED brackets with a 0.016 × 0.022 inch stainless steel archwire. On the contrary, the lowest values are provided by inserting a 0.016 × 0.016 inch NiTi archwire in a Mini Mono Bracket.

Table 2. Study materials and design.

<table>
<thead>
<tr>
<th>Bracket type</th>
<th>Manufacturer</th>
<th>Bracket material</th>
<th>Bracket width (mm)</th>
<th>Ligations</th>
<th>Wire alloys</th>
<th>Wire sections (in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swiss nonligating</td>
<td>Tröster applications, Magden, Switzerland</td>
<td>Polyetheretherketone, stainless steel clip</td>
<td>2.4</td>
<td>Passive self ligation</td>
<td>Stainless steel</td>
<td>0.016 × 0.016</td>
</tr>
<tr>
<td>Bracket</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mini Mono</td>
<td>Forestadent, Pforzheim, Germany</td>
<td>Stainless steel, nickel-titanium clip</td>
<td>2.7</td>
<td>Active self ligation</td>
<td>Nickel-titanium</td>
<td>0.016 × 0.022</td>
</tr>
<tr>
<td>Active self ligation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mini Mono</td>
<td>Forestadent, Pforzheim, Germany</td>
<td>Stainless steel, nickel-titanium clip</td>
<td>2.8</td>
<td>Elastomeric ligation</td>
<td>Stainless steel</td>
<td>0.016 × 0.016</td>
</tr>
<tr>
<td>Elastomeric ligation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 1. A Frasaco model mounted on the positioning table of the orthodontic measurement and simulation system (OMSS). The torque-force sensor replaced the right central incisor and displays a rotation of +20°.
Table 3 depicts the torque loss of brackets by engaging various types of archwires in their slot. SPEED Brackets combined with 0.016 × 0.022 inch stainless steel archwire demonstrated the lowest torque loss values, in accordance with the maximum moment data. On the other side, the highest torque loss is expressed by the insertion of a 0.016 × 0.016 inch NiTi archwire in Mini Mono Brackets. Figures 2 and 3 show bar graphs of the various bracket-wire combinations sorted by wire and bracket type.

Two-way ANOVA indicated significant interaction between bracket and archwire type. Therefore, independent Tukey post hoc comparisons tests were conducted in order to specify group inferences and the normal distribution of the obtained data as shown in Tables 4 and 5. All tests have provided a high significance (P < 0.05).

**Discussion**

Nowadays, we are going through an era of evidence based dental practice, which demands integration of systematic assessments of clinically relevant scientific evidence with clinical expertise, as well as patient’s treatment needs and preferences.
minimum values of 5 Nmm (28) have also been reported as sufficient for torquing a maxillary incisor. The moments generated in the current study approach principally the limits set from previous investigations, including though some restrictions. In particular, all the evaluated moments exert greater magnitude than 10 N with an exception of both Mini Mono and Brilliant brackets combined with a 0.016 × 0.016 inch NiTi archwire, where the values reach 9.4 Nmm and may generate insufficient moments. On the contrary, SPEED brackets demonstrate enhanced torque capabilities by expressing torsional movement of 17 Nmm by application of a 0.016 × 0.016 inch NiTi and reaching magnitude of 35 Nmm by ligation of a 0.016 × 0.022 inch stainless steel archwire.

According to the literature, sources of torque variations may stem from the archwire cross-sectional diameters, bracket slot dimension, torque play, and ligation modes. Additional variables related to the torque efficiency include the archwire edge bevelling, interbracket distance, material properties, such as torsional stiffness and elastic modulus; manufacturing processes including milling or casting; anatomical discrepancies, for instance tooth size and curvature of the crowns; as well as clinical procedures, i.e. bracket placement, thickness of the adhesive.

Torque expression, by default, can be achieved by filling the bracket slot and gradually increasing the archwire dimensions during orthodontic treatment. The wires evaluated in this investigation are most usually inserted as the final archwires in terms of an orthodontic treatment. In the current study the obtained results underline mainly the intercorrelation of alloy type, torque play, archwire dimension, and ligation method with the torque efficacy.

Comparative assessment of the biomechanical properties of stainless steel and Nitinol alloy wire has been in previous investigations reported (10, 42). In course of the current in vitro investigation by the insertion of Nitinol archwires in the bracket slots the values of torquing moments are generally decreased, due to the partial dissipation of its activation as elastic deformation. This biomechanical behaviour can be attributed to the fact that Nitinol is considered to be a low-modulus alloy (10). The stiffness of the archwire, which for the stainless steel

Table 5. Results of the two-way analysis of variance (ANOVA) of the torque loss for the various bracket-archwire combinations included in the study. df, degrees of freedom.

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of squares</th>
<th>df</th>
<th>Mean square</th>
<th>F</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bracket * wire</td>
<td>309.851</td>
<td>9</td>
<td>34.428</td>
<td>4.683</td>
<td>0.000</td>
</tr>
<tr>
<td>Bracket</td>
<td>278.512</td>
<td>3</td>
<td>92.837</td>
<td>12.627</td>
<td>0.000</td>
</tr>
<tr>
<td>Wire</td>
<td>177.118</td>
<td>3</td>
<td>59.039</td>
<td>8.030</td>
<td>0.000</td>
</tr>
</tbody>
</table>

Figure 2. Graphics displaying the measured maximal moment/torque values (Nmm) in the various configurations included in the study.

Figure 3. Graphics demonstrating the torque loss (°) of brackets under the insertion of various types of archwires included in the study.
is four times higher as for the Nitinol alloy, can modulate the torque expression generated from the activation of such a wire engaged to the preadjusted slot. Meling and Odegaard have also exhaustively investigated the torque variation as a function of alloy and wire size (20). The reduced stiffness of the NiTi wires in comparison to the stainless steel ones has been reported to account for the requirement that wire torque should exceed 25 degrees to induce a deactivation plateau.

However, it should be stressed that in terms of the current study material properties impose a great effect on the expression of torque capabilities, as in all cases stainless steel archwire demonstrates enhanced torsional moments than any NiTi archwire. Moreover, filling the slot by incrementally increasing wire cross-sections has been one of the principal mechanotherapeutic sequence of treatment protocols. Alternative treatment schemes, such as variable-modulus orthodontics, advocate engaging the slot in the initial stages of treatment with a low-modulus wire alloy and progressively increasing the stiffness of the wire instead of its size (43).

Additionally, another potential factor which can lead to fallacy of transferring the ideal torque prescribed in the bracket is illustrated through the play of the wire in the relevant and the neighbouring slots, reducing thus the treatment efficacy on the bracket-archwire complex. Self-ligating brackets, which exert greater torque magnitudes, by inserting in their slot a 0.16 x 0.22 inch archwire present the lowest values of torque play. On the contrary, conventional brackets, which display decreased torque capabilities in comparison to the self-ligating ones, appear to develop an extended torque play between the slot and the inserted archwire.

However, despite the fact that most of the bracket systems are characterised from specific prescriptions, there have been noticed discrepancies between theoretical calculations and experimental configurations of torque play. The inconsistency in torque loss can be attributed to dimensional inconsistency of archwire and bracket, as well as to rounded wire edges (14, 20). All slots display a rough surface with imperfections, porosity, and microstructural defects through the introduction of metal particles, grooves, and striations in terms of variations in the manufacturing processes of brackets. As a result, a dimensional accuracy of the slot wall can occur leading subsequently to constrictions in the full engagement of the wire in the slot walls. It should be also underlined, that the divergence of the experimental data can stem from 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 as well as the potential effect of other auxiliaries or treatment utilities (28).

All archwires used in the conventionally ligating bracket system were fixed with elastic ligatures. According to a previous study of Hirai the effect of elastic/metal ligation type in order to predict the generation of moments and subsequently the torque play.

Conventionally ligating brackets demonstrate lower torque capabilities in comparison to the self-ligating ones and in particular to SPEED brackets. In particular, the active self-ligating bracket manifests superior torque effectiveness than the passive self-ligating bracket. Moreover, according to the obtained results an evident dependence of the torque expression is displayed on the dimension of the archwire.

### Conclusion

The interpretation of the outcome of the current experimental investigation illustrates the interdependence of the bracket system and the type of archwire alloy in order to predict the generation of moments and subsequently the torque play.

Conventionally ligating brackets demonstrate lower torque capabilities in comparison to the self-ligating ones and in particular to SPEED brackets. In particular, the active self-ligating bracket manifests superior torque effectiveness than the passive self-ligating bracket. Moreover, according to the obtained results an evident dependence of the torque expression is displayed on the dimension of the archwire.

## References

4. Germaine, N., Bentley, B.E., Jr and Isaacson, R.J. (1989) Three biologic variables modifying faciolingual tooth angulation by straight-wire appli-