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Effects of various types of orthodontic wires and brackets on the torque expression by wire twisting

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서울대학교 대학원
치의과학과 치과생체재료과학 전공

강 혜 연

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이 논문을 치의학석사학위논문으로 제출함

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강혜연의 석사학위논문을 인준함

2014 년 12 월

위 원 장 ______________________ 인

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-ABSTRACT-

Effects of various types of orthodontic wires and brackets on the torque expression by wire twisting

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Self-ligating brackets have become widely used because of their advantages: time-saving ligation mode, full and secure wire ligation, improved oral hygiene. Despite their numerous benefits, their torque characteristics remain unknown. The purpose of this study was to investigate the torque characteristics of self-ligating brackets compared with conventional brackets using various orthodontic wires.

Four types of 0.022 inch slot orthodontic brackets were tested: the self-ligating metallic bracket (Smartclip SL3), the conventional metallic bracket (Victory Series), the self-ligating ceramic bracket (Empower Clear), and the conventional ceramic bracket (20/40 TM Ceramic). Four types of 0.019×0.025 inch orthodontic wires were used: Stainless Steel wire (Ormco), Co-Cr-Ni alloy wire (Yellow Elgiloy), and β-Ti alloy wires (β-III Ti, TitanMoly). Two brackets of each type were bonded on the two maxillary central incisors of a dental resin model. The total length of the wire was 8.0 cm, and the inter-bracket distance was 5 mm. The wires were ligated with 0.120 inch elastomeric ligatures (Ormco) into the conventional brackets. For the self-ligating brackets, clips had been closed. Wire was twisted up to 90^{o} in step of 1^{o} with the step motor, and the torque expression was recorded using a computer. Ten measurements were performed for each bracket-wire combination.

The Yellow Elgiloy wire exhibited the highest torque expression, followed by the Stainless Steel, TitanMoly, and β-III Ti wires, using either metallic or ceramic brackets (conventional and self-ligating). For the beta-titanium alloy wires, there were no significant differences in torque expressions with bracket types and materials up to 40^{o} twisting. On the contrary, for the Stainless Steel and Yellow Elgiloy wires, the torque expressions were significantly higher for the self-ligating brackets than the conventional brackets (both for metallic and ceramic brackets). Moreover, there were no significant differences between the ceramic and metallic brackets ($p>0.05$). The torque expression curves were dominated by the characteristics of the wire alloy. The self-ligating brackets have higher torque expression than the conventional brackets, for both ceramic and metallic brackets. The results showed that the ligation type and material of the bracket has less influence on the torque expression for the beta-titanium alloy wires than the Stainless Steel and Yellow Elgiloy wires. More the wire is stiffer, more the difference in torque expression between the conventional and self-ligating bracket is big.

Keywords: torque, twist, conventional bracket self-ligating bracket, ceramic bracket, metal bracket, orthodontic wire.

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Effects of various types of orthodontic wires and brackets on the torque expression by wire twisting

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I. Introduction

In orthodontics, controlled root movement is required to correct malocclusions. Torque is employed to alter the bucco-lingual inclination of teeth, particularly the maxillary incisors. The twisting between the bracket of an axially rotated tooth and orthodontic wire creates a torque moment. In 1959, Rauch described torque as ‘a moment generated by the torsion of a rectangular wire in the bracket slot’. The torque expression is the force moment providing rotation of the tooth around the bucco-lingual axis. The torque expression depends on the stiffness and size of the wire, the design and material of the bracket, the mode of ligation, the play of the wire in the angulation slot. The torque angle is the angle to which the wire has been twisted in degrees, and torque expression is defined as the torque at a given angle. The arch wire will move the root of the teeth in a buccal or lingual direction, due to the torsional load induced. For the clinician, it is difficult to determine the appropriate torque moment as there is a large possibility of arch wire-bracket combination, and only few researches have been done on the torque characteristics of various combinations. The maxillary central incisor torque in pre-adjusted appliances ranges from 12^{o} degrees in the Roth[(7)] discipline to 22^{o} for the Bioprogressive prescription.

The self-ligating brackets were introduced in 1933 by Boyd and Ford[(11)], to save time since the elastic ligatures were not available in the past. These brackets have multiple advantages: elimination of ligation, time-saving ligation mode, reduced friction, full and secure wire ligation, improved oral hygiene, and longer appointment intervals. Self-ligating brackets have been widely used, however, their torque characteristics remain unknown. In 2009, Huang *et al.*[(1)] demonstrated that self-ligating Damon (metal clip) and Speed (NiTi clip) brackets had lower torque expressions than conventional Discovery brackets (metal). They found that the stiffness of the archwire was the significant contributing factor with regard to the torque expression, and also the bracket width. Moreover, the self-ligating Speed bracket has a NiTi clip, and because of its superelastic characteristic, Speed bracket has the lowest torque moment. In 2012, Huang *et al*.(2) showed that even with the same widths, the self-ligating brackets presented lower torque capability.

The ceramic brackets have been introduced in the world of orthodontics in 1986, and they have been widely used because of their aesthetic advantage. None of the previous studies compared the effect of ligation types and materials for brackets in combination with various arch wires of different alloy.

The purpose of this study was to compare the torque capability of different types of bracket and arch wire combinations.

II. Literature review

The torque expression depends on the wire torque stiffness, the size and quality of the wire, the ligation type, the design and material of the bracket, the play of the wire in the angulation slot, the angulation. Several researches have been done about these different characteristics.

a) Different alloys used in orthodontic wires

In the 1950s, more than 300 types of Stainless Steel alloys were used for most orthodontic materials. Stainless Steel orthodontic wires typically contain chromium (17-25%), nickel (8-25%), with the balance being iron. They are very strong and stiff. Cobalt-chromium-nickel based alloy (Elgiloy) also introduced in the 1950s contain cobalt (40%), chromium (20%), iron (16%), and nickel (15%). They have similar stiffness characteristics as Stainless Steel, but have a better formability. The β-titanium alloys were introduced in the 1980s, they contain titanium (80%), molybdenum (11.5%), zirconium (6%), and tin (4.5%). Commercially pure titanium has a stiffness (102 GPa) that is about one-half of that Stainless Steel. They present several advantages and was called the almost 'perfect wire'[9]. Compared with the Stainless Steel, the β-titanium has higher springback, modulus of elasticity, formability, gentler linear forces per unit of deactivation. Those properties result in larger tooth displacements, in lighter forces.

Titanium Molybdenum (type of beta-titanium) wires have the worst coefficient of friction, and consequently, its ability to accommodate the sliding of teeth was limited. Therefore, the Stainless Steel remains the best wire in orthodontics[10]. In 1981, Kusy compared the torque expression of archwires with different alloys, and demonstrated that reduced modulus rigidity alloys are less ineffective in transmitting torque moments to brackets[9]. In 1997, Kusy explained that during the initial stage of treatment, where leveling and alignment are demanded, great range and light forces are sought: Stainless Steel, which have the best ratio of strength, stiffness and range, are suggested[10]. In the intermediate treatment stage, Kusy suggested to use the beta-titanium alloys because of their formability, springback, range, and modes forces per unit deactivation. In the final stage of the treatment, where small tooth movements are required, beta-titanium or Stainless Steel wires are both acceptable. If it is more important to have more spring range, beta-titanium alloy wire will be suggested. If it is more important to have more stiffness, stainless steel wire will be suggested.

b) Wire torque stiffness

Archambault *et al.*[14] compared the torque expression between Stainless Steel (SS), Titanium Molybdenum Alloy (TMA), and Copper Nickel Titanium (Cu-NiTi) 0.019×0.0195 inch wires in 0.022 inch slot metallic self-ligating brackets (Damon 3MX, In-Ovation-R, Speed). They used a worm-gear-driven torquing apparatus to twist the wire in the bracket. The twist angle was from 0^{o} to 51^{o}. At low twist angles ($<12^{o}$), the differences in torque expression between wires were not statistically significant, whereas at twist angles overs 24^{o}, SS wire yielded 1.5 to 2 times the torque expression of TMA and 2.5 to 3 times that of Cu-NiTi. Archambault showed that the SS wire has the largest torque expression, followed by TMA and then Cu-NiTi wire.

c) Bracket size

Sifakakis *et al.*[12] compared ten specimens of 0.017×0.025 inch and ten 0.019×0.025 inch Stainless Steel archwires (Ormco) in the low and high torque 0.018 inch slot and 0.022 inch slot brackets, respectively. The Stainless Steel wires wire ligated with 0.120 inch elastomerics (Ormco molded 'O'), and each measurement was repeated once after religation. A 15^{o} buccal root torque (-15^{o}) and then a 15^{o} palatal root torque ($+15^{o}$) were applied to the right central incisor bracket. The torque expression was measured with an OMSS (Orthodontic Measurement and Simulation System). At 15^{o} buccal root torque, the torque moment was 14.3 N·mm with a 0.017×0.025 inch SS archwire in 0.018 slot high-torque brackets, and 12.9 N·mm in low-torque brackets. For the 0.019×0.025 inch SS archwire in 0.022 inch slot brackets, the torque moment was 9.3 N·mm in the high-torque brackets, and 6.5 N·mm in the low-torque brackets. They found the same tendance at -15^{o}. The torque expression generated by the 0.017×0.025 inch archwire in the 0.018 inch slot were higher than the 0.019×0.025 inch wire in the 0.022 slot, due to torque loss. The lower torque moment measured in the 0.022 inch bracket is not a disadvantage for the clinician, since there is no scientific consensus regarding ideal torque moment. Many researches[1] recognize that 5.0 N·mm is the minimum torque required for the upper central incisor.

The elastic ligatures ensure similar ligation forces between the different bracket systems. However, their rapid force loss (50% in 24 hours) is a disadvantage. Thus, the engagement of the wire into the bracket is incomplete and flexible. If a maximum torque is demanded, steel ligatures will be preferred. Moreover, Sifakakis *et al.*[12] emphasizes that in vitro studies have limitations as the actual force system acting on the teeth will probably depend in time because of the presence of the anisotropic periodontal ligament.

d) Bracket material, Play of the wire in the bracket slot

Morina *et al.*[4] studied torque expressions on an aligned levelled maxillary arch of a Frasaco model attached to the OMSS. The objective was to investigate the torque expression of active and passive self-ligating brackets compared with metallic, ceramic, and polycarbonate edgewise bracket. They used a 0.022 inch slot brackets, 0.019×0.025 inch SS wires. The conventional metallic brackets were ligated with a Stainless Steel ligature, and for the self-ligation brackets, the clips had been closed. They were careful about the ligatures. All measurements were performed by one investigator, and the ligature wire well tightened and well adjusted: no play was obvious. A torque of 20^{o} was applied, each bracket-wire combination was measured ten times, and maximum torque expression and torque loss were investigated.

The ceramic bracket (Fascination, 35 N·mm) showed the highest torque moment, followed by the polycarbonate bracket (Brilliant, 13.5 N·mm), the conventional metal bracket (Ultratrimm, 12.3 N·mm), the self-ligating bracket (Speed and Damon, 8 N·mm and 7.8 N·mm), and the conventional metal brackets (Discovery, 7.5 N·mm). In this study, self-ligating brackets present reduced torque moment compared with the conventional ceramic brackets. Large sized slots and small sized wires contribute to increase play, thereby reducing the torque expression capacity. The slot size of the two self-ligating Speed and Damon brackets are respectively 0.54 mm and 0.59 mm, while the size of the 0.019×0.025 inch archwire is 0.48 mm. It results increased play for these brackets, thus, reduced torque moment for the self-ligating brackets. Morina[4] underlined that care must be taken to use an appropriate wire-bracket slot combination to avoid too much play with small size wires in oversized slots. Moreover, this phenomenon is emphasized by the torsional stiffness of the archwire. Reduced elastic modulus alloys (β-Ti, NiTi) are less ineffective in transmitting torque moments to brackets slots.

The highest torque expression with the ceramic brackets could be explained by the fact that the ceramic possesses the highest raw material modulus of elasticity and the increased roughness of the slot walls from the manufacturing process. Thus, there is an increased wire-slot friction. Morina[4] also noted frequent fracture of the ceramic bracket. The manufacturing and design process of the bracket also play a role in torque moment.

e) Type of ligation

Pandis *et al.*[6] did a clinical study about the maxillary incisor torque with conventional and self-ligating brackets. They finished the treatment with Stainless Steel 0.019×0.025 inch archwires with Damon2 (self-ligating brackets) and Glendora (conventional brackets). Contrary to the other studies, they concluded that there were no significant differences between the conventional and self-ligating brackets. They both seem to deliver torque equally to maxillary incisors in extraction and non-extraction cases.

In 2009, Huang compared three types of bracket[1]: self-ligating Speed (NiTi clip), self-ligating Damon MX (metal clip), and conventionally ligated Discovery. They had all the same slot size (0.022 inch), but different widths. Their widths were 2.33 mm, 2.75 mm, 3.36 mm respectively. Torque of 20^o was applied to 4 maxillary incisors with 0.018×0.025 and 0.019×0.025 inch archwires. They compared also 3 types of wire alloys (SS, TMA, and NiTi). Two types of ligation were used for the Discovery brackets: elastic and Stainless Steel wire. The torque expression is more influenced by the alloy of the wire than the wire dimension (125% increase for a 0.019×0.025 inch wire instead of a 0.018×0.025 inch SS wire, and 220% for a 0.018×0.025 inch SS wire instead of a NiTi wire). The highest torque moment (75 N·mm) was generated by the 0.019×0.025 inch SS wire, and the lowest moment (10 N·mm) by the 0.018×0.025 inch NiTi wire, using Discovery brackets with elastic ligatures. For the Speed self-ligating brackets, the highest moment (7.5 N·mm) was generated by the 0.018×0.025 inch SS wire, followed by the 0.018×0.025 inch TMA wire (3.5 N·mm), followed by the 0.018×0.025 inch NiTi wire (3.0 N·mm). Moreover, the expression was a little bit higher for the Discovery bracket with elastic ligation (34 N·mm) than the Discovery bracket with wire ligation (31 N·mm) with the 0.018×0.025 inch SS wire.

The self-ligating Damon bracket presented a higher torque moment (25 N·mm) than the Speed bracket (7.5 N·mm) for the 0.018×0.025 inch SS wire. As the self-ligating have narrower width than the Discovery bracket, it is difficult to attribute a better torque capability to the conventional bracket compared with self-ligating brackets. The highest torque moment was for the SS wire, followed by the TMA, and NiTi wire. The Discovery bracket with elastic ligature had the largest torque expression, followed by the Discovery bracket with wire ligature, followed by the self-ligating Damon bracket, followed by the self-ligating Speed bracket.

Most of previous researches studied with one single bracket, but in brackets-archwire system, the torque moment tends to lower, because of the play of the wire in neighboring brackets. Moreover, the Speed bracket showed a low torque expression, because of the superelastic behavior of the active clip. The play of the wire in the bracket slot is an important factor influencing the torque behavior more than the type of ligation. The play of the wire decreases the torque moment, so using an appropriate wire sequence is more important than the type of ligation[6].

In 2012, Huang *et al.*[2] investigated the torque capacity of conventional and self-ligating brackets under the effect of bracket width and free wire length. Three types of 0.022 inch slot brackets were compared: the conventional Discovery, the self-ligating Damon 3MX, and the self-ligating Speed. Speed, Damon, and Discovery brackets had different widths, their widths were 2.33 mm, 2.75 mm, and 3.36 mm respectively. But with the software ADOR-3D, the Damon and Speed brackets were rescaled, and had the same width as the Discovery bracket (3.36 mm). Four brackets were bonded from the left upper incisor to the right upper canine. The Discovery brackets were ligated with conventional elastic ligature, and the self-ligating ones, the clips had been closed. The total wire length at the upper right incisor was kept constant at 12 mm for all bracket types. The wire length was increased from 14 mm to 16 mm in steps of 2 mm for the Discovery brackets. A torque of 20^{o} was given with 0.018×0.025 and 0.019×0.025 inch wires. They used 3 types of wires (SS, TMA and NiTi). For the Discovery brackets, the SS wire presented the highest torque expression, followed by the TMA, and NiTi wire. The wide Damon brackets in combination with the respective wire generated similar torque expression to the Discovery brackets, whereas the normal Damon brackets produced low torque expression. This can be explained by a reduction in the free wire length of the wider bracket.

Wider brackets have bigger torque expression. However, the wide Speed bracket showed low torque expression due to the superelastic NiTi clip. The maximum torque transmission is reduced significantly. Brackets with increased width showed a 15% increase in torque expression, compared to the original sized brackets. But even with the same width, conventional brackets showed higher torque expression compared with the self-ligating brackets. Moreover, as the inter-bracket distant decreases, the torque expression increases. Clinically, the treatment effect will decrease if the dental arch is wide.

These days, ceramic brackets are widely used, because they give the patient an aesthetic advantage during the treatment. But during the positioning of the wire into the bracket, frequent ceramic fracture is observed. The fracture of ceramic brackets is frequent when applying twisting forces, and is a major problem for the orthodontics. It causes increased chair time, and the bracket fragment can be aspired by the patient, which makes a discomfort for the patient. The fracture can be explained by the absence of plastic deformation in the ceramic material[4].

III. Materials and method

Four types of orthodontic brackets were used in the study: the self-ligating metallic bracket Smartclip SL3 (3M Unitek, USA), the conventional metallic bracket Victory Series (3M Unitek, USA), the self-ligating ceramic bracket (Empower Clear Bracket, American Orthodontics, USA), and the conventional ceramic bracket (20/40 TM Ceramic bracket, American Orthodontics, USA). All brackets had a 0.022 inch slot size. The width of the brackets were 3.0 mm for Smartclip, 3.52 mm for Victory Series, 3.28 mm for Empower Clear Bracket, 3.85 mm for TM Ceramic bracket. The Smartclip SL3 self-ligating metal bracket has a NiTi clip, which is fatigue resistant and has an optimal shape memory. The Empower Clear bracket, self-ligating bracket, has also a NiTi clip.

Four types of 0.019×0.025 inch orthodontic wires were used: beta-titanium alloy wires (β-III Ti wires, 3M Unitek, USA; TitanMoly wire, G&H, USA), Stainless Steel wire (Ormco, USA), and Co-Cr-Ni based alloy wire (Yellow Elgiloy, RMO, USA).

Two brackets of same type were bonded on the two maxillary central incisors of a dental resin model. The inter-bracket distance was 5 mm and the orthodontic wire (8.0 cm) was inserted into the bracket slot. The orthodontic wires were ligated with 0.120 inch elastomeric ligatures (Molded ‘O’, Ormco, USA) into the conventional brackets, the ligation was well tightened, and no play was obvious. For the self-ligating brackets, clips had been closed.

The custom-made orthodontic torque measurement device was used to measure torque expression. This device was controlled by a personal computer and consists of an orthodontic bracket mounting plate, a torque gauge (Mark-10, Electromatic Equip. Co., Cedarhurst, NY, USA), a signal controller, and a step motor (Fig. 1). The wire was rotated by a step motor, torque data were recorded every 1^{o} from 0^{o} to 90^{o}. The torque expression and the rotating angle were recorded at the same time by the computer. All measurements were performed by one investigator and 10 measurements were performed for each bracket-wire combination.

Fig. 1. The custom-made orthodontic torque measurement device.

IV. Results

a) Ceramic brackets

Table 1 shows the torque expression at various twist angles for the combinations of ceramic bracket with different wire. The effect of the wire material was clearly observed. The Yellow Elgiloy wire exhibited the highest torque expression, followed by the Stainless Steel wire, beta-titanium alloy wires (TitanMoly and β-III Ti) using both conventional ceramic brackets and self-ligating ceramic bracket. The torque expressions were dominated by the characteristic of the wire alloy. At 60^{o} twisting angle, the highest moment (15.5 N·mm) was generated by the Yellow Elgiloy wire with the self-ligating bracket, and the lowest moment (7.81 N·mm) by the β-III Ti wire with the conventional bracket. The Yellow Elgiloy and Stainless Steel wires with the ceramic bracket have a torque expression that is about 2 times higher than the β-III Ti wires.

The Stainless Steel and Yellow Elgiloy wires with ceramic brackets showed similar torque expression curves. For the Yellow Elgiloy wire-ceramic bracket combination, the torque moment was significantly higher (15%) for the self-ligating bracket than the conventional bracket ($p<0.05$). For the Stainless Steel wire-ceramic bracket combination, the torque moment was significantly higher (22%) for the self-ligating bracket than the conventional bracket ($p<0.05$). The β-III Ti and TitanMoly wires with ceramic bracket generated also similar torque moment curves. For the β-III Ti wire-ceramic bracket combination, the torque expression was slightly higher (9%) for the self-ligating bracket than the conventional bracket. For the TitanMoly wire-ceramic bracket combination, the torque expression was also slightly higher (9%) for the self-ligating bracket than the conventional bracket.

Table 1. Torque (N·mm) formed by twisting orthodontic wire in ceramic bracket

Wires	Ceramic brackets	Twist angle (°)					
		10	20	30	40	60	80
β-III Ti alloy	conventional	1.45± 0.08	2.64± 0.24	3.92± 0.39	5.16± 0.63	7.81± 0.77	10.71± 1.07
	self-ligating	1.44± 0.11	2.61± 0.24	3.84± 0.26	5.13± 0.26	8.64± 0.42	12.37± 0.45
TitanMoly alloy	conventional	1.52± 0.17	3.01± 0.11	4.29± 0.20	5.82± 0.17	8.59± 0.29	12.08± 0.30
	self-ligating	1.35± 0.23	2.40± 0.16	3.67± 0.30	5.22± 0.65	8.71± 0.66	12.44± 0.64
Yellow Elgiloy	conventional	2.19± 0.42	3.98± 0.61	5.67± 0.68	7.78± 0.56	13.20± 1.10	19.42± 1.12
	self-ligating	1.89± 0.31	3.66± 0.42	5.71± 0.76	8.61± 0.81	15.50± 0.70	22.50± 0.83
Stainless Steel.	conventional	1.75± 0.32	3.27± 0.64	4.91± 0.78	6.75± 0.97	11.25± 2.20	17.47± 2.89
	self-ligating	1.71± 0.42	3.36± 0.69	4.98± 0.69	7.87± 0.82	14.42± 0.79	21.27± 0.99

b) Metallic bracket

The Yellow Elgiloy wire exhibited the highest torque expression, followed by the Stainless Steel wire, beta-titanium alloy wires (TitanMoly and β-III Ti) using both conventional metallic brackets and self-ligating metallic bracket (Table 2). The torque expressions were also dominated by the characteristic of the wire alloy.

Table 2. Torque (N·mm) formed by twisting orthodontic wire in metal bracket

Wires	Metal brackets	Twist angle (°)					
		10	20	30	40	60	80
β-III Ti alloy	conventional	1.41± 0.00	2.80± 0.30	3.88± 0.40	4.94± 0.43	7.35± 0.66	10.42± 0.82
	self-ligating	1.21± 0.25	2.28± 0.30	3.32± 0.33	4.49± 0.46	7.71± 0.75	11.32± 0.83
TitanMoly alloy	conventional	1.49± 0.23	3.00± 0.60	4.18± 0.73	5.25± 0.97	7.99± 0.97	11.44± 1.30
	self-ligating	1.25± 0.22	2.41± 0.32	3.74± 0.53	5.27± 0.76	9.15± 0.82	13.13± 0.95
Yellow Elgiloy	conventional	2.02± 0.26	3.82± 0.82	5.80± 1.48	8.09± 2.02	13.54± 2.47	19.64± 2.41
	self-ligating	2.23± 0.29	4.82± 0.85	7.78± 1.27	10.90± 1.44	17.65± 1.39	24.00± 1.39
Stainless Steel.	conventional	1.59± 0.21	3.18± 0.25	4.86± 0.46	6.69± 0.81	11.60± 1.92	18.37± 2.05
	self-ligating	1.56± 0.38	3.05± 0.91	5.46± 1.31	8.66± 1.72	15.83± 2.08	23.05± 1.98

The Stainless Steel and Yellow Elgiloy wires with metallic brackets showed similar torque expression curves. For the Yellow Elgiloy wire with metallic bracket combination, the torque expression was significantly higher for the self-ligating bracket than the conventional bracket. For the Stainless Steel wire-metallic bracket combination, the torque expression was also significantly higher for the self-ligating bracket than the conventional bracket. The beta–titanium alloy wires (β-III Ti and TitanMoly) with metallic bracket generated similar torque expression curves. For the β-III Ti wire with metallic bracket combination, the torque expression was slightly higher for the self-ligating bracket than the conventional bracket. For the TitanMoly wire with metallic bracket combination, the torque expression was 17% higher for the self-ligating bracket than the conventional bracket.

The Yellow Elgiloy and Stainless Steel wires with the metallic bracket have a 2 times higher torque expression than the TitanMoly and β-III Ti wires. Wires with high stiffness showed higher torque expressions than the wires with low stiffness.

Figs. 2-9 show curves of the simulated twisting angle - torque moment characteristics with various type of wires (Stainless Steel, Yellow Elgiloy, β-III Ti, TitanMoly), bracket types (metallic or ceramic), and ligation type (self-ligation or conventional). The figures show the effect of the different ligation method on the relationship of twisting angle and torque expression.

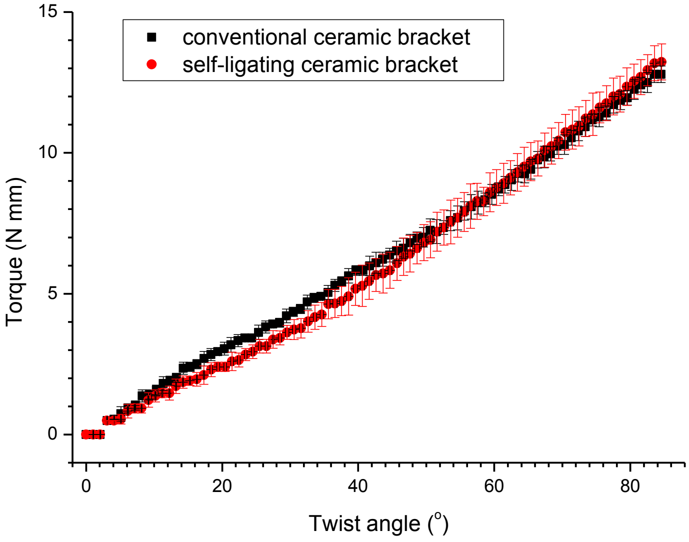

Fig. 2. Torque expression curves of the TitanMoly wire with ceramic bracket.

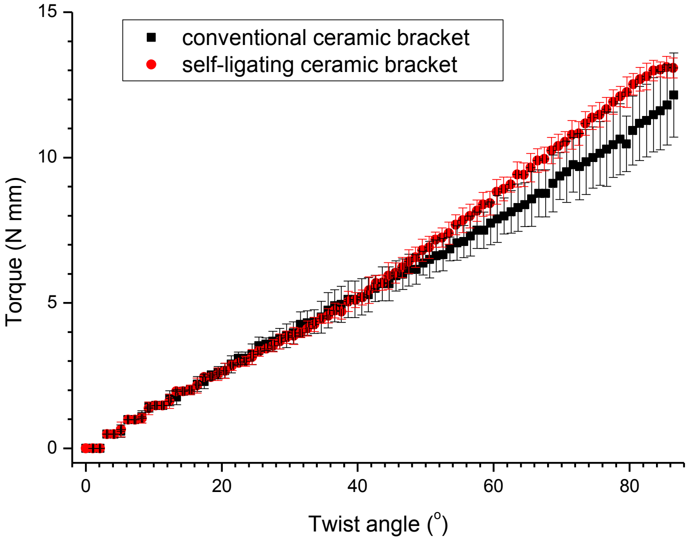

Fig. 3. Torque expression curves of the β-III Ti wire with ceramic bracket.

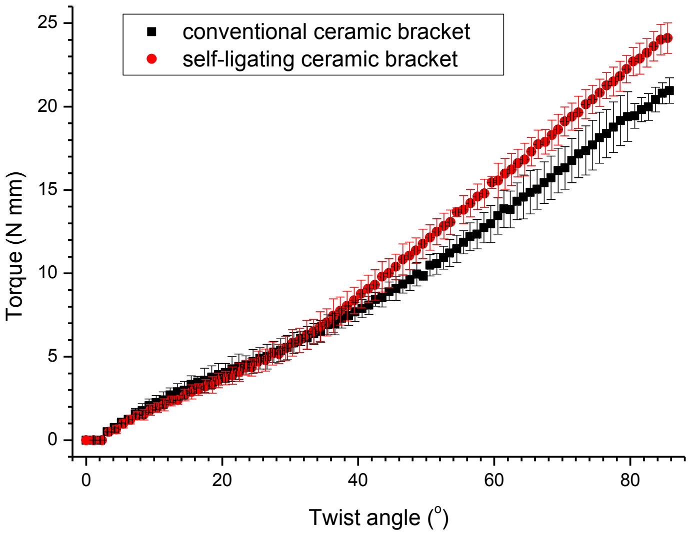

Fig. 4. Torque expression curves of Yellow Elgiloy wire with ceramic bracket.

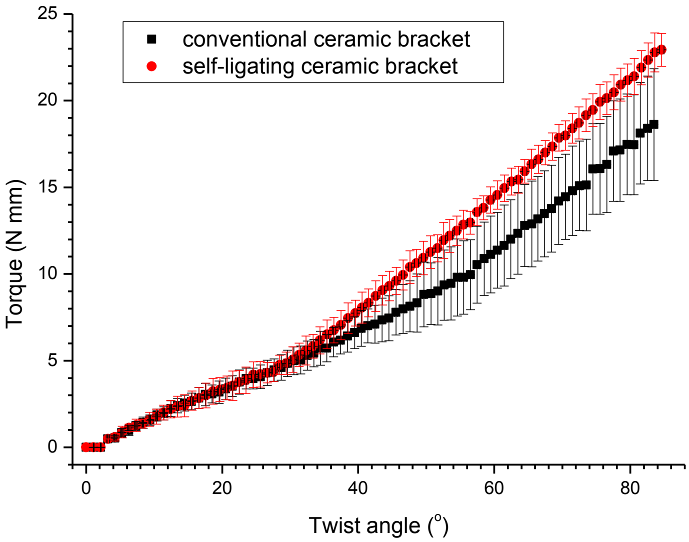

Fig. 5. Torque expression curves of the SS wire with ceramic bracket.

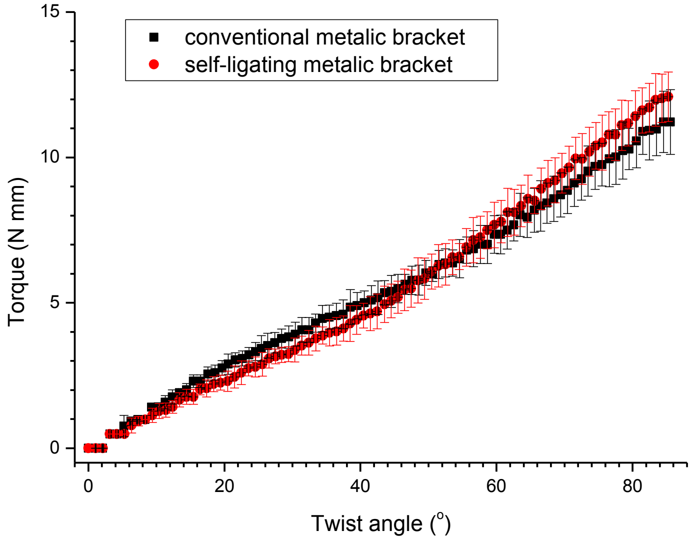

Fig. 6. Torque expression curves of the β-III Ti wire with metallic bracket.

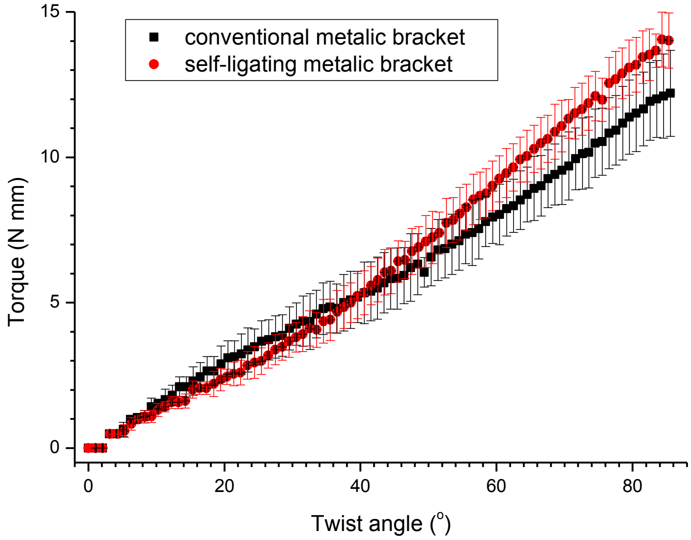

Fig. 7. Torque expression curves of the TitanMoly wire with metallic bracket.

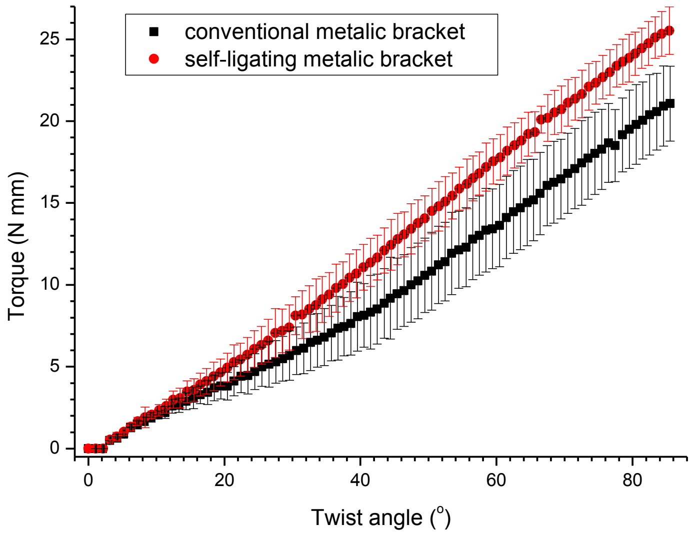

Fig. 8. Torque expression curves of Yellow Elgiloy wire with metallic bracket.

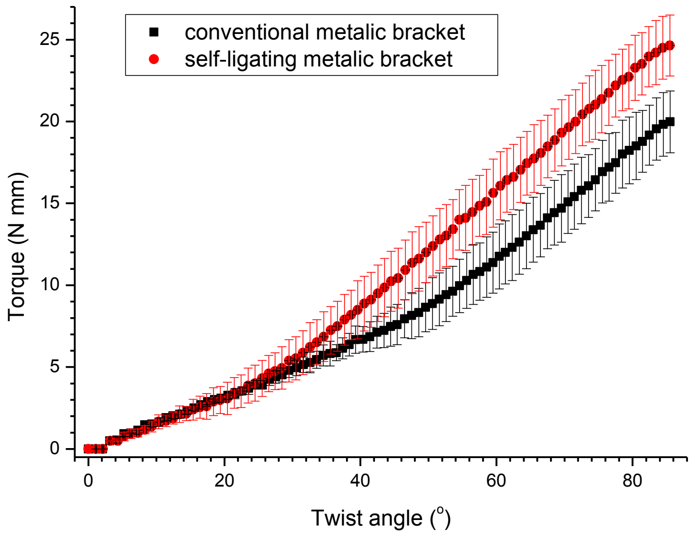

Fig. 9. Torque expression curves of the SS wire with metallic bracket.

In general, there were no significant differences in the torque expression between the conventional and self-ligating bracket for the beta-titanium alloy wires (β-III Ti and TitanMoly), For the stiff wires (Stainless Steel and Yellow Elgiloy) torque expressions were significantly higher for the self-ligating brackets than for the conventional brackets.

At the beginning of the torsion, the torque moment generated by the self-ligating bracket was lower than the conventional bracket, but the self-ligating brackets created a larger torque moment than the conventional ones with the increase of twisting angle.

For the conventional brackets, there were no significant differences of torque expression between the metallic and ceramic brackets ($p>0.05$).

For the β-III Ti and Elgiloy wire with self-ligating bracket combination, metallic brackets showed a higher torque moment than the ceramic brackets ($p<0.05$). But for the TitanMoly and Stainless Steel wire with self-ligating bracket combination, there were no significant differences between the metallic and ceramic brackets ($p>0.05$).

But during the positioning of the Stainless Steel and Yellow Elgiloy wire into the ceramic bracket, we observed frequent ceramic fracture.

β-Ti alloy wires (β-III Ti and TitanMoly) presented similar torque moment up to 40^{o} of twisting regardless of bracket type or bracket material ($p>0.05$). Up to 40^{o} of torsion, Elgiloy wire generated higher torque moment than the Stainless Steel wire ($p<0.05$).

V. Discussion

The orthodontic companies give a variety of bracket-archwire combination with different torque prescriptions. Archambault[14] and Morina.[4] have chosen to twist up to 51^o and 20^o, respectively. In general, the maximum twist angle used in clinics is less than 20^o, however, wire was twisted up to 90^o in this study. Clinicians sometimes pre-twist archwires to add torque expression. From 20^o of twist, all the graphs show a linear relationship between the torque expression and twist angle.

The results of this study suggest that self-ligating brackets have higher torque expressions compared with conventional brackets for both ceramic and metallic brackets. The highest moment (26.0 N·mm) was generated by the Elgiloy wire with the metallic self-ligating bracket, and the lowest moment (10.4 N·mm) by the β III Titanium wire with the metallic conventional bracket.

The results of this study were not in agreement with a recent in-vitro investigation: Huang *et al.*[1] showed that the conventional bracket (Discovery) had higher torque expression than the self-ligating brackets (Damon, Speed brackets). They explained this phenomenon by the narrower width of the self-ligating brackets. As the self-ligating have narrower width than the Discovery bracket, it is difficult to attribute a better torque capability to the conventional bracket compared with self-ligating brackets. As the Discovery brackets had wider width, the play between the wire and the bracket was decreased, thus the torque expression was increased. So three years later, in 2012, Huang[2] investigated the torque capacity of conventional and self-ligating brackets, which were rescaled to have the same width. But even with the same width, conventional brackets with elastomeric ligatures showed higher torque expression compared with the self-ligating bracket: the wide Speed bracket showed low torque expression due to the superelastic NiTi clip, the maximum torque transmission is reduced significantly.

In this study, all brackets had a 0.022-inch slot size, but their widths were all different: 3.0 mm for Smartclip, 3.28 mm for Empower Clear Bracket, 3.52 mm for Victory Series, and 3.85 mm for TM Ceramic bracket. If the bracket width had a great influence on torque expression as Huang's research[2], in this study, the highest torque would be expressed by the TM Ceramic bracket, followed by the Victory Series, Empower Clear Bracket, and Smartclip bracket, respectively. But in this study, for all wire alloys, the highest torque was generated by the Smartclip bracket (self-ligating metallic), followed by Empower Clear bracket (self-ligating ceramic), Victory Series (conventional metallic), and TM Ceramic bracket (conventional ceramic). The TM Ceramic bracket, which has the highest width, generated the lowest torque expression.

This controversial result could be attributed by the complexity of the experimental configuration, and the many factors needed to be controlled. The torque expression is also influenced by the closure of the ligation and the investigator-dependent variable could not be excluded. Moreover, Smartclip and Empower Clear brackets are passive self-ligating brackets, whereas Speed bracket is an active self-ligating bracket. Badawi *et al.* [3]also showed that the Speed bracket had the lowest torque expression compared with Smartclip bracket.

Moreover, the play of the wire in the bracket slot is an important factor influencing the torque expression: appropriate wire sequences are better than specialized clip techniques to ligate the archwire in the bracket slot.

The 0.019×0.025 inch wire could be considered as the appropriate size for

0.022 inch bracket for the maximum torque expression. The excessive play with smaller wire sizes in oversized slots should be avoided. The play of the wire with the bracket was more decreased for the self-ligation bracket than the ligation with elastomeric wire, thus the torque expression was bigger for the self-ligation bracket.

The Yellow Elgiloy archwire exhibited the highest torque expression, followed by the Stainless Steel, TitanMoly, and β-III Ti, using metallic brackets (conventional and self-ligating). Similar results for the ceramic brackets were observed: the Elgiloy archwire exhibited the highest torque moment, followed by the Stainless Steel, TitanMoly, and β-III Ti. As Yellow Elgiloy and Stainless Steel are the stiffest material followed by TitanMoly, and β-III Ti, it was a predictable result. Wires with a low stiffness caused less transmitting torque expression to brackets. This is consistent with the result of Archambault *et al*.[11] that the Stainless Steel wire had the largest torque expression, followed by TMA and then NiTi, in metallic self-ligating brackets.

For the β-III Ti and TitanMoly wires, the torque expression was similar between the conventional metallic and self-ligating metallic brackets (self-ligating lightly higher). Similar results for the conventional ceramic and self-ligating ceramic brackets were observed. On the contrary, for the Stainless Steel and Yellow Elgiloy wires, the torque expressions were significantly higher for the self-ligating brackets than the conventional brackets (both for metallic and ceramic brackets). The torque expression curves are dominated by the characteristics of the wire alloy. More the wire alloy is stiff, more there is a significant difference in the torque expression between the self-ligating and conventional bracket. The torque expression curves seem to be dominated by the stiffness of the archwires rather than the ligation type. On the one hand, less stiff alloys such as β-III Ti and TitanMoly have a similar effect on the wire play of self-ligating and conventional brackets, thus a similar torque expression. On the other hand, more stiff alloys such as Stainless Steel and Yellow Elgiloy have a different effect on self-ligating and conventional brackets' wire play. Furthermore, there were no significant differences between the ceramic and metallic bracket. Morina *et al.*[4], however, showed that the Fascination 2 ceramic bracket had the highest torque expression among the metallic, ceramic, and plastic brackets. It could be explained by the fact Fascination 2 possessed the highest modulus of elasticity.

The Smartclip and Empower Clear self-ligating brackets showed also similar torque expression. They both have a Ni-Ti clip and their load deflection curves were consistent with what would be expected of a nickel-titanium alloy. For the Smartclip-Stainless Steel archwire combination at 12^{o}, 24^{o}, 36^{o} and 48^{o} of torsion, the torque expressions were 1 N·mm, 5 N·mm, 9 N·mm and 13 N·mm, respectively. This result was consistent with the Badawi *et al*'s[3] study, who also investigated torque expression with a 0.019×0.025 Stainless Steel wire into a Smartclip bracket.

The torsion of Stainless Steel and Yellow Elgiloy wire into the ceramic brackets caused frequent fracture of the ceramic brackets. During the torsion of the wires, stresses are concentrated on the slot of the ceramic bracket, and as ceramic material have brittleness without plastic deformation, the ceramic bracket breaks. The bracket fragment can be inhaled by the patient, which makes a discomfort for the patient, and an increased chair time.

We have to underline that in vitro studies have limitations as the actual force system acting on the teeth will probably depend in time because of the presence of the anisotropic periodontal ligament.

VI. Conclusion

The torque expression curves are dominated by the characteristics of the wire alloy. The width of the bracket has no great influence on the torque control. The self-ligating brackets seem to have better torque control, compared with conventional brackets, for both ceramic and metallic brackets. The results showed that the type (material) and design of the bracket has less influence on the torque expression for the beta-titanium alloy wires than the Stainless Steel and Elgiloy wires.

There were no significant differences in the torque expression between the conventional and self-ligating brackets for the beta-titanium alloy wires (β-III Ti and TitanMoly). On the contrary, for alloys with higher elastic modulus (Stainless Steel and Elgiloy wires), torque expressions were significantly higher for the self-ligating brackets than the conventional bracket. More the stiffness of the wire is, more there is a significant torque difference between the conventional and self-ligating brackets. Moreover, there were no significant differences between the ceramic and metallic brackets, but during the positioning of the Stainless Steel and Yellow Elgiloy wires into the ceramic bracket, we observed frequent ceramic fracture.

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-국문초록-

브라켓 유형과 교정용 호선의 재질이 토오크 생성에 주는 영향

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심미성이 좋고, 사용이 편리하며, 교정력을 일정하게 전달할 수 있는 다양한 자가-결찰 브라켓이 소개되면서 일반 브라켓과 비교한 연구는 많이 보고되었지만, 토오크 형성에 주는 영향을 비교한 연구는 거의 없는 상황이다. 본 논문에서는 세라믹과 금속으로 제조한 자가-결찰 브라켓과 일반 브라켓이 토오크 형성에 주는 영향을 비교하기 위하여 다양한 재질의 브라켓과 교정용 호선을 조합하여 비틀림 각도에 따라 생성되는 토오크를 평가하고자 하였다.

자가-결찰 브라켓은 0.022 inch 슬롯의 금속 브라켓인 Smartclip SL3 (3M Unitek)와 세라믹 브라켓인 Empower Clear (American Orthodontics)를 사용하였고, 일반 브라켓으로 금속 브라켓인 Victory Series (3M Unitek)와 세라믹 브라켓인 20/40 TM (American Orthodontics)을 사용하였다. 교정용 호선은 0.019×0.025 inch 스테인리스 강 호선 (Ormco), 코발트-크롬-니켈계 합금 호선 (Elgiloy),

베타-티타늄 합금 호선인 β-III 호선 (3M Unitek)와 TitanMoly 호선 (G&H)을 사용하였다. 상악 전치부 모델에 브라켓 2 개를 5 mm 간격으로 접착시킨 후 일반 브라켓의 경우는 0.120 inch elastomeric ligature (Ormco)로 8.0 cm 호선을 고정하였고, 자가-결찰 브라켓의 경우는 호선을 삽입한 후 클립을 닫아 고정하였다. 브라켓에 삽입한 호선을 자체 제작한 토오크 측정장치에 연결한 다음 호선을 1° 간격으로 90°까지 비틀면서 생성되는 토오크를 측정하였다. 각 실험군당 10 회 측정하여 평균값과 표준편차를 구하였으며 다음의 결과를 얻었다.

1) 브라켓 재질과 유형 (금속/세라믹, 자가-결찰/일반)에 상관없이 Elgiloy 호선이 가장 높은 토오크를 생성하였고, SS, TitanMoly, β-III Ti 호선 순서로 낮은 토오크를 보였다.

2) 베타-티타늄 합금인 TitanMoly 호선과 β-III Ti 호선은 브라켓 재질과 유형에 상관없이 유사한 토오크 생성 양상을 보였다.

3) Elgiloy 호선과 SS 호선 경우에는 브라켓의 재질에 상관없이 자가-결찰 브라켓이 일반 브라켓 보다 유의하게 높은 토오크를 생성하였다.

4) 브라켓의 재질은 생성되는 토오크 값에 유의한 영향을 주지 않았으나 ($p>0.05$), 세라믹 브라켓의 경우 실험 도중에 브라켓이 파절되는 경우가 많았다.

주요어: 토오크, 비틀림, 일반 브라켓, 자가-결찰 브라켓, 세라믹 브라켓, 금속 브라켓, 교정용 호선

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