Original Article

Evaluation of torque moment in esthetic brackets from bendable alloy wires

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ABSTRACT

Objectives: To examine the torque moment that occurs between esthetic brackets and bendable alloy (stainless steel [SS], titanium-molybdenum [Ti-Mo], and titanium-niobium [Ti-Nb]) wires.

Materials and Methods: This study examined ceramic (CR), zirconium oxide (ZC), polycarbonate (PC), and conventional metallic brackets (MT) (upper, 0.018-inch and 0.022-inch slots) combined with SS, Ti-Mo, and Ti-Nb wires using elastic module ligation. The torque moments delivered by various wire and bracket combinations were measured using a torque gauge apparatus. The wire torque angles at 5–40° were examined.

Results: The torque value increased in the order of CR, ZC, MT, and PC brackets for both 0.018-inch and 0.022-inch slots. The fracture points of the CR and ZC brackets combined with SS and Ti-Mo wires were approximately more than 30° and 35°, respectively. No fracture points were detected in the combination of ZC brackets and Ti-Nb wires.

Conclusions: The current study identified the material characteristics of CR, ZR, and PC brackets during torque tooth movements. The present results demonstrate a characteristic combined effect between different esthetic brackets and bendable alloy wires. (*Angle Orthod.* 2021;91:656–663.)

KEY WORDS: Torque moment; Third-order bend; Esthetic bracket; Bendable wire; Fracture point; Dental materials

INTRODUCTION

The number of adult patients treated in orthodontic clinics has been increasing; therefore, orthodontists have to use more esthetic treatment appliances in the clinic. The development of orthodontic appliances with acceptable esthetics for patients and optimal technical performance for orthodontists are indispensable for obtaining optimal treatment outcomes.

In the past few decades, three major esthetic brackets—ceramic brackets using an alumina injection mold, zirconium oxide ceramic brackets, and polycarbonate brackets—have been developed and are commonly used clinically.[1–6] However, these esthetic brackets have some material characteristic-related issues, such as the inferior physical and mechanical properties of polycarbonate brackets and the low fracture toughness of ceramic brackets.[1,2,5,7–12] During orthodontic treatment, brackets are subjected to various mechanical forces. In particular, torque moments applied to the anterior teeth are likely to cause bracket fracture or bonding failure.[1,2,5,7–11] Therefore, a comprehensive understanding of torque expression in esthetic brackets is essential for treatment outcomes.

In orthodontic wires, the desirable characteristics include a large springback, low stiffness, high formability, continuously stored energy, biocompatibility,

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Accepted: January 2021. Submitted: August 2020.
Published Online: April 6, 2021

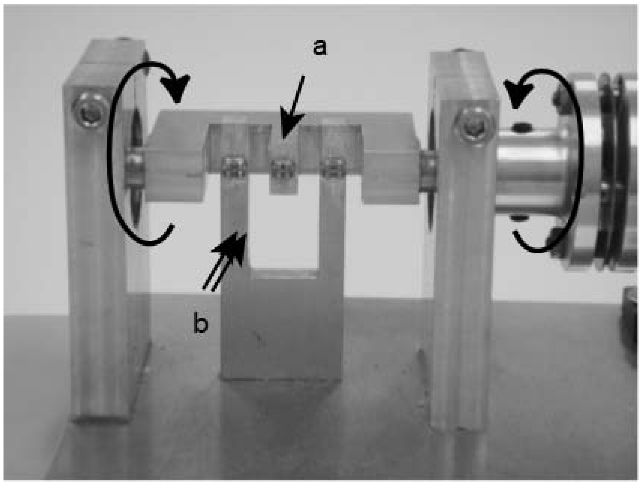

Figure 1. The torque testing apparatus consisted of a torque transducer connected to a torque gauge. The single arrow (a) indicates a part of the rotation arm that was placed on the lateral incisor bracket and was rotatable to measure the torque moment. The double arrows (b) indicate the fixed arm, which was placed on the central incisor bracket and canine bracket.

environmental stability, and low surface friction.[13] Bendable alloy wires, including titanium-molybdenum (Ti-Mo) alloy and titanium-niobium (Ti-Nb) alloy wires, which have characteristics between those of nickel and titanium (Ni-Ti) alloy and stainless steel (SS) wires, have recently become available.[13]

Previous studies evaluated the torque moments delivered by various orthodontic bendable wires and metallic brackets at the target tooth and demonstrated that the torque moment increased with larger degrees of torque and larger wire sizes depending on the combination of orthodontic wires and brackets.[14,15] Although these results can help in understanding the amount of third-order bends for wire-bracket-ligation combinations, little information is available on the resistance of esthetic brackets to torsional forces from bendable orthodontic wires. Thus, the purpose of this study was to measure the torque moment delivered by bendable orthodontic wires and three esthetic brackets (ceramic, zirconium oxide ceramic, and polycarbonate brackets) and analyze the torque moment compared with those with metallic brackets.

MATERIALS AND METHODS

Four types of brackets made from different materials were used with maxillary central incisor, lateral incisor, and canine brackets, with two slot sizes of 0.018 × 0.025-inch (0.018-inch) and 0.022 × 0.028-inch (0.022-inch). Ceramic brackets made using an injection mold (CR; Signature, JM Ortho, Tokyo, Japan), zirconium oxide ceramic brackets (ZC; Sincere brace, JM Ortho), and polycarbonate brackets (PC; Alice, JM Ortho) were selected as esthetic brackets (n = 5 for each). A metallic bracket (MT; Mesh Bracket, Tomy International Inc, Tokyo, Japan) (Figure 1D) was also used as a control.

The following three different bendable wires were used for each slot bracket: 0.017 × 0.025-inch Ti-Mo alloy wires (TMA, Ormco Japan, Tokyo, Japan), Ti-Nb alloy wires (GUMMETAL, Rocky Mountain Morita Co, Tokyo, Japan), and SS wires (Shiny Bright Wire, TP Japan, Tokyo, Japan) for the 0.018-inch slot brackets, and 0.019 × 0.025-inch Ti-Nb, Ti-Mo, and SS wires for the 0.022-inch slot brackets. Ligation was performed using an elastomeric ligature (Las-Tie; Tomy International Inc).

To measure the torque moment, an experimental apparatus consisting of a torque transducer (Kyowa Electronic Instrument Co, Tokyo, Japan) and a torque gauge (Kyowa Electronic Instruments Co.) was used (Figure 1).[14,15] The simulated central incisor, lateral incisor, and canine brackets were placed on one side of the apparatus, and a circular protractor was placed on the other side to measure the torque moment (Figure 1). For each bracket–wire combination, the torque moments were measured with a torque application of 5–40° at 5° intervals.

After the measurements, the data were statistically analyzed using the Statistical Package for Social Sciences (version 8.0 for Windows, SPSS Japan Inc, Tokyo, Japan). Statistical analyses were performed using analysis of variance multiple comparison tests and post hoc Tukey's honestly significant difference test. A probability of $P < .01$ was considered significant.

RESULTS

Torque Expression From 0.017 × 0.025-Inch Wires in 0.018-Inch Slot Brackets

The torque moments from the SS wires were not significantly different between the CR and ZC brackets for torque applications of 5–25° (Figure 2A and Table 1). The torque expressions of these two brackets were significantly larger than those of the MT and PC brackets for torque applications of 10–25°. However, the fracture point of the CR bracket was at 30°, and the fracture resistance torque of CR brackets was the lowest among the four different brackets. The ZC brackets fractured at an applied torque of 35°. The PC brackets showed a significantly smaller torque moment than those of the other three brackets at more than 10° of torque application. No fracture was found in the MT or PC brackets for torque applications of 40°.

The torque moments of the CR and ZC brackets from the Ti-Mo wires were approximately 10–40% smaller than those of SS wires at applied torque of 10–

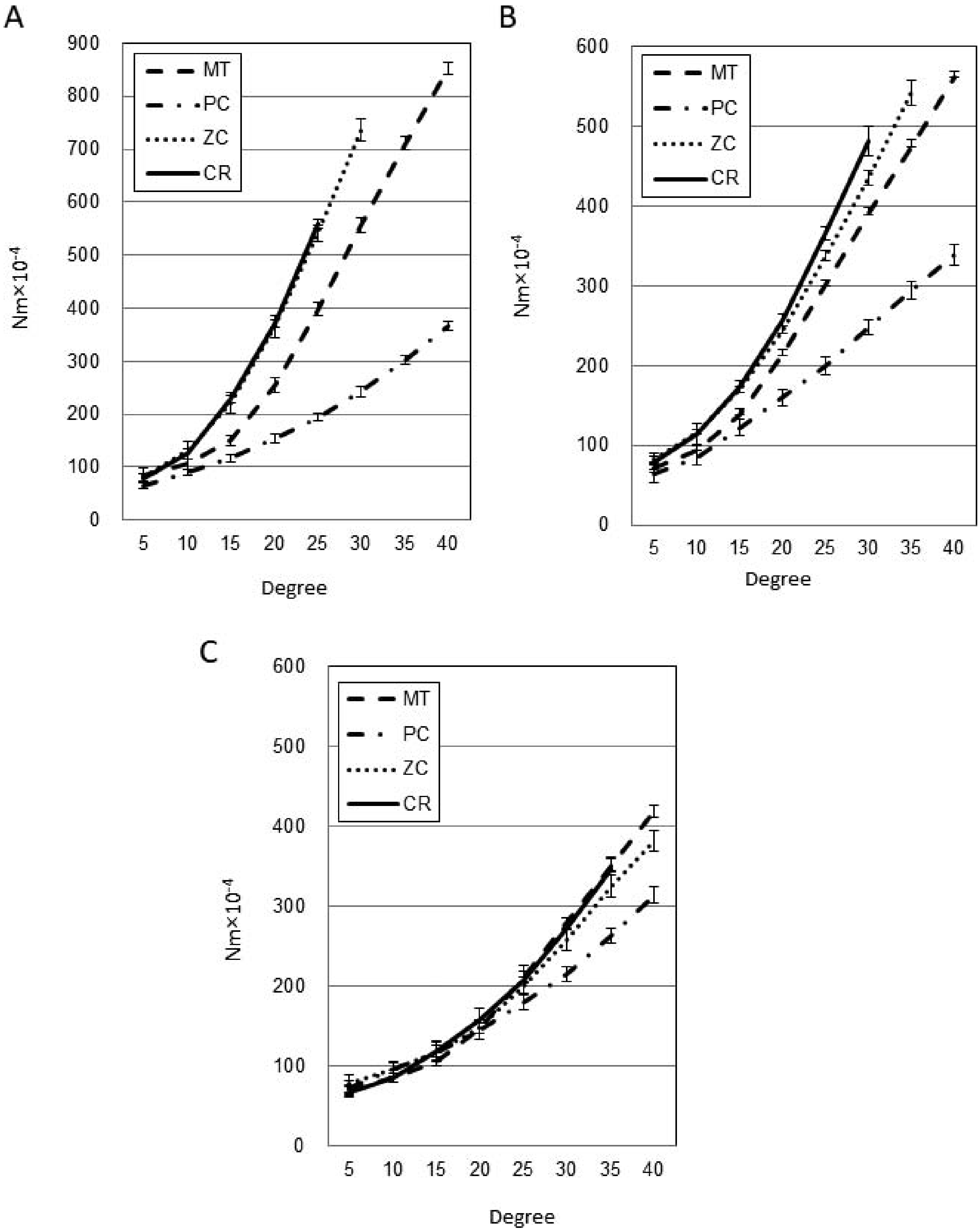

Figure 2. (A) Torque expression of a 0.017 × 0.025-inch SS wire in a 0.018-inch slot. (B) Torque expression of a 0.017 × 0.025-inch Ti-Mo wire in a 0.018-inch slot. (C) Torque expression of a 0.017 × 0.025-inch Ti-Nb wire in a 0.018-inch slot.

Table 1. Torque Expressions of a 0.017 × 0.025-Inch Wire in a 0.018-Inch Slot[a]

		5°		10°		15°		20°		25°		30°		35°		40°	
Wire	Bracket	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
SS	MT	85.8[e]	11.4	106.0[cde]	10.2	151.3[cde]	10.0	254.3[ce]	14.1	398.6[ce]	11.4	555.6[e]	14.3	710.8[e]	13.1	853.1[e]	11.3
	CR	80.1[e]	8.5	125.0[be]	8.7	228.7[be]	7.6	371.7[bde]	7.2	560.0[bde]	8.5	–	–	–	–	–	–
	ZC	80.9[e]	7.7	131.9[be]	16.4	221.8[be]	19.6	365.3[ce]	20.6	541.3[ce]	15.3	736.4[e]	19.8	–	–	–	–
	PC	65.1[bcd]	6.7	89.9[bcd]	6.1	117.0[bcd]	6.2	154.7[bcd]	7.7	194.1[bcd]	6.7	243.0[bd]	9.4	302.3[b]	7.2	366.0[b]	7.8
Ti-Mo	MT	71.4	8.1	94.7[cde]	7.0	139.1[cde]	6.0	214.2[cde]	5.7	301.1[cde]	6.7	390.3[cde]	8.4	474.8[de]	8.0	562.3[e]	6.7
	CR	78.8[e]	12.0	114.0[be]	14.0	173.9[be]	7.8	257.1[be]	6.8	366.0[bde]	7.9	481.3[bde]	18.1	–	–	–	–
	ZC	82.1[e]	4.9	116.8[be]	3.0	169.7[be]	3.4	244.7[be]	4.9	337.5[bce]	6.9	435.7[bce]	8.8	542.3[be]	15.7	–	–
	PC	63.5[cd]	11.2	84.3[bcd]	9.9	122.4[bcd]	9.7	160.0[bcd]	9.9	199.7[bcd]	10.4	248.4[bcd]	9.2	293.5[bd]	11.1	339.4[b]	13.0
Ti-Nb	MT	68.1	15.0	85.4	15.5	108.4	13.5	147.8	8.4	210.7[e]	10.2	276.2[e]	5.5	348.7[e]	7.9	411.1[e]	11.2
	CR	66.8	7.4	86.0	9.8	119.2	13.6	158.3[e]	15.4	207.2[e]	18.9	272.5[e]	14.2	346.4[e]	16.2	–	–
	ZC	76.2	13.4	95.1	9.0	117.5	9.6	152.7	9.4	207.3[e]	10.0	268.4[e]	13.9	337.8[e]	19.4	396.5[e]	19.5
	PC	72.6	10.4	96.0	8.3	117.6	12.2	144.6[c]	10.2	181.2[bcd]	9.9	215.7[bcd]	9.2	263.7[bcd]	8.7	314.2[bd]	10.0

[a] n = 5, unit: Nm × 10^{-4}. SD indicates standard deviation.
[b] vs MT: $P < .05$.
[c] vs CR: $P < .05$.
[d] vs ZC: $P < .05$.
[e] vs PC: $P < .05$.

25°, and the reduction rates increased with increasing torque angle (Figure 2B and Table 1). The decrease in the torque moments of the PC bracket was less than 10% at torque applications of 5–40°. At 5° torque application, the torque moments of all brackets were in the same range. At more than 10° of torque application, the CR and ZC brackets showed a significantly larger torque moment than those of the MT and PC brackets. Compared with that of the ZC brackets, the torque expression of the CR bracket was significantly larger at 25–30°. The PC brackets had the smallest torque moment at torque applications of 10–40°. The CR brackets were fractured at 35° of torque application, and the fracture point of the ZC brackets was at 40°. There were no fracture points in the MT and PC brackets for 40° of torque application.

The Ti-Nb wires had approximately 30–60% smaller torque moments than those of the SS wires at an applied torque of 10–25°; they were also less than those of the Ti-Mo wires. At 5–20° of torque application, the torque expressions were almost the same among the four measured brackets (Figure 2C and Table 1). At 25–35°, the PC brackets showed significantly smaller torque moments than those of the other brackets. CR brackets fractured at 40° torque application, whereas the other brackets had no fracture points at 40° torque application.

Torque Expression From 0.019 × 0.025-Inch Wires in 0.022-Inch Slot Brackets

The torque expressions from SS wires in the CR bracket were significantly larger than those of the other brackets at 10–25° torque application (Figure 3A and Table 2), whereas those of the ZC bracket showed the second largest values. The torque moments were significantly larger in the ZC bracket than in the MT and PC brackets at 10–30° torque application. The torque expression of PC brackets was the lowest and significantly lower than that of the MT bracket at 25–40°. The fracture point of the CR bracket was at 30° and that of the ZC bracket was at 35° with the SS wire. There were no fracture points for the MT or PC brackets.

The torque expressions of CR and ZC brackets with Ti-Mo wires were approximately 10–40% smaller than those with SS wires at applied torque of 10–25°, and the reduction rates increased with increasing torque angle (Figure 3B and Table 2). The decrease in the torque moments of the PC bracket was approximately 10% at torque applications of 5–40°. The torque expression of the CR bracket was significantly larger than those of the ZC, MT, and PC brackets at 20–30° torque application. There were no significant differences between the CR and ZC brackets at 5–15°. The fracture point of the CR bracket was at 35° and that of the ZC bracket was at 40°. The fracture point was not detected in the MT or PC brackets.

For the CR and ZC brackets, the torque moments from Ti-Nb wires were approximately 30–60% smaller than those of SS wires at 10–25° torque application. The decrease in the torque moments of the PC bracket was 10–30% at torque applications of 5–40° (Figure 3C and Table 2). The torque expression of the CR bracket was the highest, followed by the ZC bracket, whereas the values for the PC bracket were the smallest. The torque values of the CR bracket were significantly larger than those of the ZC, MT, and PC brackets at 10–35°. The torque expressions of the ZC brackets were also significantly larger than those of the MT and PC brackets at 10–35° torque application. The torque expression of PC brackets was the smallest at 5–40°.

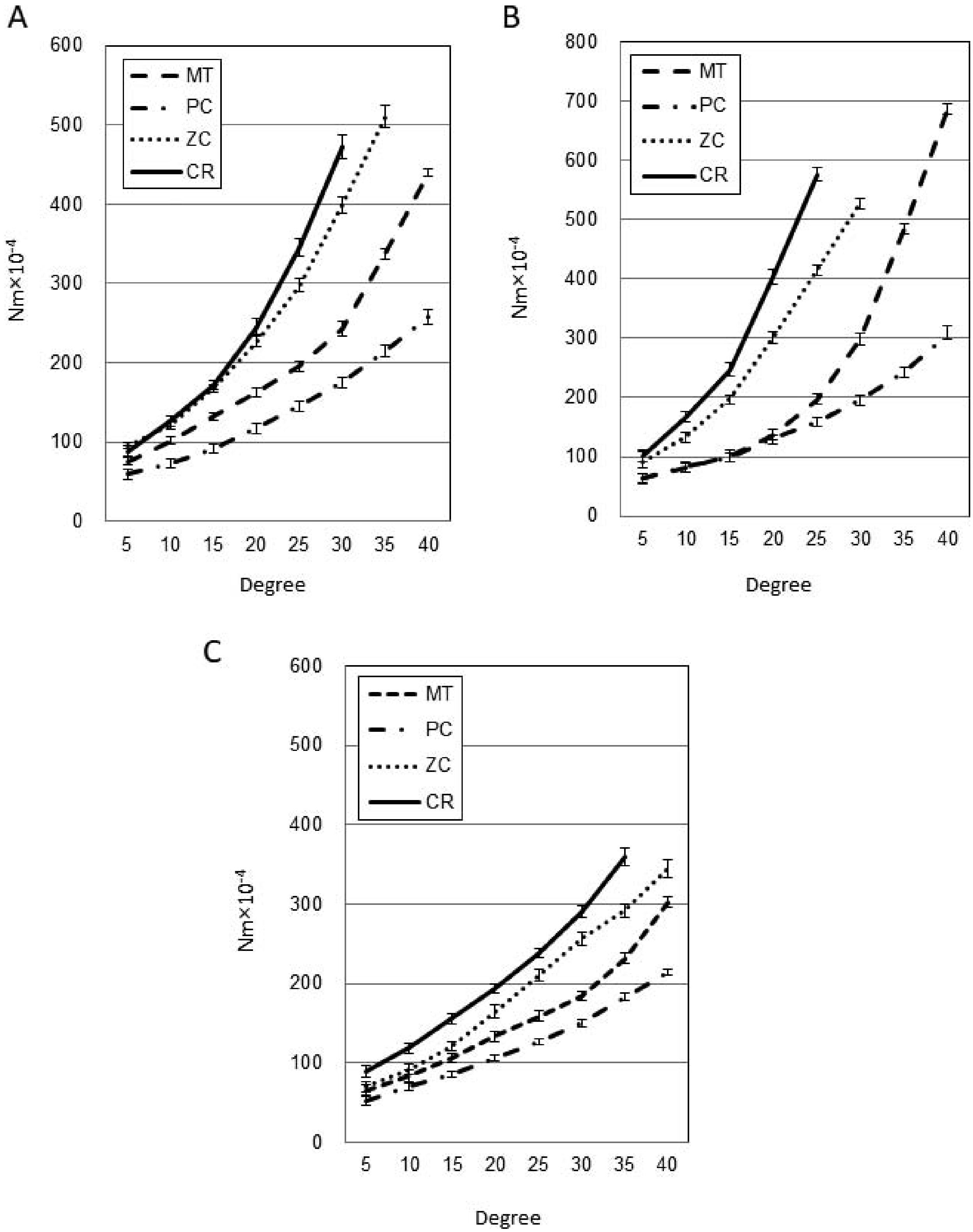

Figure 3. (A) Torque expression of a 0.019 × 0.025-inch SS wire in a 0.022-inch slot. (B) Torque expression of a 0.019 × 0.025-inch Ti-Mo wire in a 0.022-inch slot. (C) Torque expression of a 0.019 × 0.025-inch Ti-Nb wire in a 0.022-inch slot.

Table 2. Torque Expressions of a 0.019 × 0.025-Inch Wire in a 0.022-Inch Slot[a]

		5°		10°		15°		20°		25°		30°		35°		40°	
Wire	Bracket	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
SS	MT	63.3[cd]	9.0	81.7[cd]	9.0	101.3[cd]	8.9	137.4[cd]	9.3	196.4[cde]	8.7	297.9[de]	9.6	484.9[e]	9.0	686.2[e]	8.4
	CR	101.0[be]	10.5	166.8[bde]	8.8	246.8[bde]	11.2	403.1[bde]	11.7	576.3[bde]	10.6	–	–	–	–	–	–
	ZC	90.9[be]	17.7	133.6[bce]	6.9	198.2[bce]	6.1	301.4[bce]	8.6	414.8[bce]	9.2	527.1[be]	7.4	–	–	–	–
	PC	64.4[cd]	7.1	82.6[cd]	5.4	99.2[cd]	7.1	130.1[cd]	6.2	159.5[bcd]	6.9	196.2[bd]	8.5	243.2[b]	8.2	306.1[b]	15.3
Ti-Mo	MT	76.1[cde]	5.1	101.6[cde]	4.8	132.2[cde]	5.2	163.1[cde]	5.9	195.8[cde]	6.3	243.4[cde]	9.4	337.9[de]	6.6	438.9[e]	4.7
	CR	88.8[be]	6.3	127.3[be]	6.4	172.6[be]	6.2	245.1[bde]	10.2	345.9[bde]	11.1	472.8[bde]	14.9	–	–	–	–
	ZC	95.9[be]	4.4	121.0[be]	4.4	167.7[be]	5.3	227.2[bce]	6.5	297.6[bce]	8.2	399.4[bce]	10.5	510.4[be]	14.5	–	–
	PC	59.5[bcd]	7.4	73.7[bcd]	6.0	92.2[bcd]	5.9	118.0[bcd]	6.5	146.0[bcd]	6.6	175.8[bcd]	6.6	215.6[bd]	7.2	258.1[b]	8.9
Ti-Nb	MT	64.9[e]	7.8	83.5[cde]	7.1	106.2[cde]	6.1	133.4[cde]	6.7	158.9[cde]	6.6	184.9[cde]	5.8	231.8[de]	6.8	302.2[de]	6.6
	CR	88.8[e]	7.1	118.8[bde]	6.8	155.5[bde]	6.6	193.2[bde]	5.9	238.5[bde]	6.1	290.7[bde]	7.5	358.9	11.1	–	–
	ZC	70.0[e]	6.7	92.0[bce]	6.9	120.9[bce]	6.4	164.7[bce]	7.7	210.6[bce]	8.2	256.2[bce]	7.8	291.6[be]	8.2	344.6[be]	11.2
	PC	52.5[bcd]	6.3	70.2[bcd]	4.8	85.6[bcd]	4.3	105.6[bcd]	4.1	126.7[bcd]	3.8	150.0[bcd]	3.9	183.3[bd]	4.3	215.0[bd]	3.7

[a] n = 5, unit: Nm × 10^{-4}.
[b] vs MT: $P < .05$.
[c] vs CR: $P < .05$.
[d] vs ZC: $P < .05$.
[e] vs PC: $P < .05$.

The fracture point of the CR bracket was 35°. The other brackets, including the ZC bracket, had no fracture points with the Ti-Nb wires.

In addition, the current study investigated the difference in torque expression between the 0.018-inch slot and the 0.022-inch slot of esthetic brackets. The 0.018-inch slot CR brackets combined with SS, Ti-Mo, or Ti-Nb wires had a smaller torque expression than that of the 0.022-inch slot brackets (Table 3). In contrast, the 0.018-inch slot ZC and PC brackets combined with SS, Ti-Mo, or Ti-Nb wires had a larger torque expression than those of the 0.022-inch slot brackets at higher torque degrees (Table 3).

DISCUSSION

The current study was designed to evaluate the mechanical resistance of various esthetic brackets to orthodontic torsional forces and investigate the torque moments induced by various combinations of esthetic brackets and bendable orthodontic wires. Although the fracture and deformation resistance to torsional force of ZC brackets has been reported,[16] the torque expression of the ZC bracket under orthodontic torque was not previously clarified. In addition, the Ti-Nb wire, a bendable elastic alloy wire, was recently developed and is commonly used in clinical orthodontics. A previous study measured the torque moment delivered by the Ti-Nb wire and a SS bracket at the target tooth and compared it with those of other orthodontic wires: Ni-Ti and Ti-Mo wires.[14] However, limited information was available on the torque moment delivered by the Ti-Nb wires and esthetic brackets at various torque applications. The present study was the first to examine the torque moments delivered from the Ti-Nb wires and esthetic brackets. This may provide more insight into possible wire–bracket combinations that provide adequate torque control of the anterior teeth.

Table 3. Comparison of Statistical Analyses of Torque Expressions Between 0.018-Inch and 0.022-Inch Slots

Wire	Bracket	5°	10°	15°	20°	25°	30°	35°	40°
SS	CR	a	a	a	a	a	–	–	–
	ZC	NS[b]	NS	c	c	c	c	–	–
	PC	NS	NS	c	c	c	c	c	c
Ti-Mo	CR	a	a	NS	NS	NS	NS	–	–
	ZC	NS	NS	NS	c	c	c	c	–
	PC	NS	c	c	c	c	c	c	c
Ti-Nb	CR	a	a	a	a	a	a	NS	–
	ZC	NS	NS	NS	NS	NS	NS	c	c
	PC	c	c	c	c	c	c	c	c

[a] $P < .05$: 0.018-inch slot < 0.022-inch slot.
[b] NS indicates nonsignificant.
[c] $P < .05$: 0.018-inch slot > 0.022-inch slot.

The present results showed that the fracture resistance of the CR bracket to torsional force was 360–560 Nm × 10^{-4}, which was almost the same as that of the ZC bracket (390–560 Nm × 10^{-4}). The fracture resistance of the CR brackets has previously been reported.[1,16] Regarding the fracture resistance of the ZC bracket to torsional force, the only available information is from a study by Alrejaye et al.[16] Their study reported that the ZC bracket had the highest torsional strength among the tested esthetic brackets, including the CR bracket.[16] By contrast, the present results showed that the ZC brackets had similar or lower resistance to torsional force compared with that of the CR brackets. A possible explanation for this difference was that, in the previous study, torque moments were measured using an experimental apparatus connected to only one bracket, whereas the current study used an original experimental apparatus that had three brackets to represent the interbracket distance and the play between the bracket and wire. This difference may also have been caused by different manufacturing components or production techniques. In contrast, there were no fracture points in the PC bracket in these bendable wires. However, according to previous studies[2–4] and the current results, the PC brackets showed the smallest torque moment of the three esthetic brackets.

Among the bendable wires, the Ti-Nb wire had the lowest elastic modulus, and the torque moments generated by the third-order bend between the wire and bracket was smaller than that of the other bendable wires.[15] This means that the Ti-Nb wires have an advantage in producing a sustained torque expression on the anterior teeth during tooth movement. The present study indicated that the ZC brackets showed no fracture points at 40° torque application when using Ti-Nb wires, although the ZC brackets fractured at 35° torque application with SS wires and at 40° with Ti-Mo wires. The CR bracket had a fracture point with lower torque application than did the ZC bracket, even though Ti-Mo is a highly elastic material. In other words, these results showed that the CR bracket was easily fractured at a lower torque than was the ZC bracket. Regarding the comparison between the CR and ZC brackets, the current study results demonstrated that the torque expressions of the ZC bracket were smaller than those of the CR bracket; however, the fracture points of the ZC brackets were higher than those of the CR brackets for all bendable wires. Therefore, this suggests that the ZC bracket was superior to the CR bracket when considering the fracture point. The combination of ZC brackets and Ti-Nb wire may provide continuous and effective torque correction of the anterior teeth.

The comparison between the torque expression of 0.018-inch and 0.022-inch stainless steel brackets is a critical topic. Sifakakis et al.[17,18] investigated the torque efficiency of different sizes of either SS or Ti-Mo alloy arch wires in 0.018-inch and 0.022-inch brackets and demonstrated statistically significant differences. The present results were also consistent with those of previous studies.[17,18] As a new finding, the 0.018-inch slot CR bracket combined with SS, Ti-Mo, or Ti-Nb wires exhibited smaller torque expressions than those of the 0.022-inch slot brackets, whereas those of the 0.018-inch slot ZC and PC brackets combined with SS, Ti-Mo, or Ti-Nb wires were larger than the torque expressions of the 0.022-inch slot brackets (Table 3).

A previous study reported that the optimum torque between the MT bracket and SS wire was approximately 100–200 Nm $\times$ 10^{-4},[14] which was calculated using data from previous research.[19–22] The hypothesized optimum torques were provided by twisting the SS and Ti-Mo wires at approximately 10–15° and the Ti-Nb wire at 15–20°. In addition, the optimum torques for the PC bracket were generated by twisting the SS and Ti-Mo wires at 15–25° and the Ti-Nb wire at 20–35°. Noticeably, there was a difference between the optimum torques for the PC bracket of the 0.018-inch slot and 0.022-inch brackets by twisting the SS, Ti-Mo, and Ti-Nb wires. These results could provide clinical information on the active optimum torque moment. Clinical torque expression involves a more accurate simulation of loading, approximation of material behavior, and variations in the geometries of the periodontal tissue, bone, and tooth shape, including tooth contact. However, this hypothesized optimal torque will enable clinicians to ensure effective tooth movement during orthodontic torque movements. These findings may contribute to improving torque correction in the anterior teeth.

CONCLUSIONS

- The torque value of the CR bracket was the highest, followed by those of the ZC, MT, and PC brackets for both 0.018-inch and 0.022-inch slot brackets.
- The decrease in torque moments of the Ti-Mo and Ti-Nb wires from those of the SS wire were larger with the CR and ZC brackets than with the PC brackets.
- The CR bracket had a fracture point at lower degrees of torque application than those of the ZC bracket in all bendable alloy wires, and the ZC brackets showed no fracture at 40° torque application when using Ti-Nb wires.
- The results demonstrate the characteristic combined effect of various cosmetic brackets and bendable alloy wires; the combination of the ZC brackets and Ti-Nb wire may effectively achieve torque correction in anterior teeth.

ACKNOWLEDGMENT

We thank Editage (www.editage.com) for English-language editing.

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