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Measurements of the torque moment in various archwire–bracket–ligation combinations

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SUMMARY The torque moment generated by third-order bends is important for tooth movement. The purpose of this study was to measure the torque moment that can be delivered by various archwire and bracket combinations at the targeted tooth. Stainless steel (SS) upper brackets with 0.018 and 0.022 inch slots, two sizes of nickel–titanium (Ni-Ti) alloy wires, and three sizes of SS wires for each bracket were used. The wire was ligated with elastics or wire. The torque moment delivered by the various archwire–bracket–ligation combinations was measured using a torque gauge. Statistical analysis was undertaken using analysis of variance (multiple comparison tests and *post hoc* using Tukey's honestly significant difference test.

The torque moment increased as the degree of torque and wire size increased. There was no significant difference in torque moment between the SS and Ni-Ti wires at lower or higher than 40 degrees torque. The torque moment with wire ligation was significantly larger than that with elastic ligation with 0.016 × 0.022 and 0.017 × 0.025 inch Ni-Ti wires in the 0.018 inch slot brackets and the 0.017 × 0.025 and 0.019 × 0.025 inch SS and Ni-Ti wires in the 0.022 inch slot brackets. However, there was no significant difference in torque moment between either ligation method when using the full slot size wires.

Introduction

In clinical orthodontics, torque expression is an important determinant for treatment outcome (Isaacson *et al.*, 1993). In particular, correct buccolingual inclination of the anterior teeth is essential for providing acceptable occlusal relationships (Jarabak and Fizzell, 1972; Proffit, 2007). Torque expression can be achieved by filling the bracket slot and gradually increasing the archwire dimensions during orthodontic treatment (Reitan, 1957, 1985). Therefore, until the archwire fills the slot, a considerable percentage of the torque built into the bracket is lost because of the play between the archwire and bracket slot (Burstone *et al.*, 1961; Burstone, 1994). There are a number of reports in the literature in which the theoretical and/or measured torque moments between wire and bracket have been calculated (Wainwright, 1973; Lee, 1995a,b, 1996).

As there is a considerable discrepancy between the theoretical and the measured bracket/archwire torque moment (Isaacson *et al.*, 1993), there may be a discrepancy between experimental and clinical torque expression. This can be due to the influence of the play between the adjacent bracket and wire on the torque expression at the target tooth. However, most previous studies have not considered this influence, which would enable determination of the effective torque moment for the expected torque motion (Burstone *et al.*, 1961; Martuccio, 1969; Wainwright, 1973; Burstone, 1994; Lee, 1995a,b, 1996). Thus, the purpose of this study was to measure the torque moment delivered by various archwire, bracket, and ligation combinations at the target tooth.

Materials and methods

Stainless steel (SS) upper incisor standard edgewise twin brackets (Super mesh standard edgewise bracket; Tomy International Inc., Tokyo, Japan) with a 0.018 × 0.025 inch slot (0.018 inch slot; $n = 5$) and 0.022 × 0.028 inch slot (0.022 inch slot; $n = 5$) were used. Five different wires were used for each slot bracket: 0.016 × 0.022, 0.017 × 0.025, and 0.018 × 0.025 inch SS wires (SUS wire; Dentsply–Sankin KK, Tokyo, Japan) and 0.016 × 0.022 and 0.017 × 0.025 inch super elastic nickel–titanium alloy (Ni-Ti) wires (Dentsply–Sankin KK) for the 0.018 inch slot brackets and 0.017 × 0.025, 0.019 × 0.025, and 0.0215 × 0.028 inch SS wires and 0.017 × 0.025 and 0.019 × 0.025 inch Ni-Ti wires for the 0.022 inch slot brackets.

The measuring apparatus consisted of a torque transducer (Kyowa Electronic Instrument Co., Tokyo, Japan) connected to a torque gauge (Kyowa Electronic Instruments Co.; Figure 1a). The simulated central incisor (bracket width:

3.2 mm), lateral incisor (bracket width: 2.6 mm), and canine (bracket width: 2.6 mm) SS brackets were placed on one side (Figure 1b and 1c) and a circular protractor to measure torque moment on the other (Figure 1d). The simulated lateral incisor of the central rod (Figure 1b and 1c) was rotatable and the other two posts were fixed on the base as the central incisor and canine (Figure 1b and 1c). Three of the brackets (central incisor, lateral incisor, and canine) were positioned in the same line of the slot to the archwire, i.e. 0 degree angulation and 0 moment. The interbracket distance was determined to be 6 mm (Feldner *et al.*, 1994). To align and set the brackets, a full size SS wire was used before they were set on the jigs (Figure 1c). The torque moment was measured using two different ligation methods: elastic ligation (Las-Tie; Tomy International Inc.) and wire ligation (0.010 inch; Tomy International Inc.). During measurement, the temperature was kept constant at 23°C and the humidity was 50 per cent.

Five bracket sets were prepared: central incisor, lateral incisor, and canine. Each set was measured five times using different wires. The measurement of torque moment was performed five times for each bracket–wire combination. The data were statistically analysed using the Statistical Package for Social Sciences (Version 8.0 for Windows; SPSS Japan Inc., Tokyo, Japan). Statistical analysis was performed using analysis of variance multiple comparison tests and *post hoc* Turkey's honestly significant difference test. $P < 0.01$ was considered statistically significant.

Results

Comparison between SS and Ni-Ti wire in 0.018 inch slot brackets

For the 0.016 × 0.022 inch wires, ligated with an elastic ligature, there was no significant difference in torque moment between the SS and Ni-Ti wires at 5 and 10 degrees of applied torque (Figure 2a, Tables 1 and 2). With 15–40 degrees of applied torque, the moment of the 0.016 × 0.022 inch SS wires ligated with elastics was approximately 1.4–1.8 times larger than that of Ni-Ti wires. For the 0.016 × 0.022 inch wires with wire ligation, there was no significant difference between the moments of SS and Ni-Ti wires at 5 and 10 degrees. However,

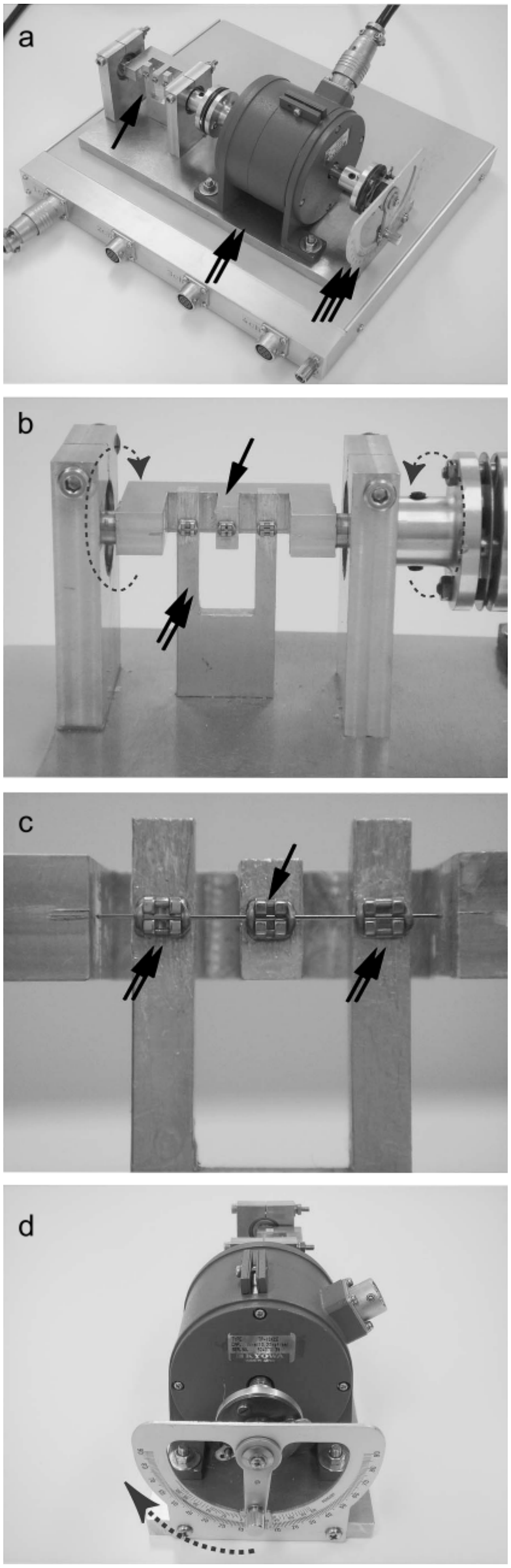

Figure 1 (a) The torque testing apparatus consisted of a torque transducer connected to a torque gauge. The single arrow indicates the part of the bracket and wire for measurement, the double arrows a part of the torque transducer, and the triple arrows a part of the circular protractor, which was also rotatable to measure torque moment. (b) A part of the bracket and wire was used to calculate toque moment. The simulated lateral incisor as the central rod was rotatable (single arrow) and another two posts were fixed on the base (double arrows). The single arrow indicates a part of the rotation arm, which was placed in the lateral incisor bracket and was rotatable to measure torque moment, and the double arrows indicate the fixed arm, which was the central incisor and canine bracket. (c) A high magnification image of the rotation arm and fixed arm. The rotation arm was placed in the lateral incisor brackets (single arrow), and the fixed arm were placed in the central incisor and canine brackets (double arrows). (d) A circular protractor was placed on the other side to measure torque angulations.

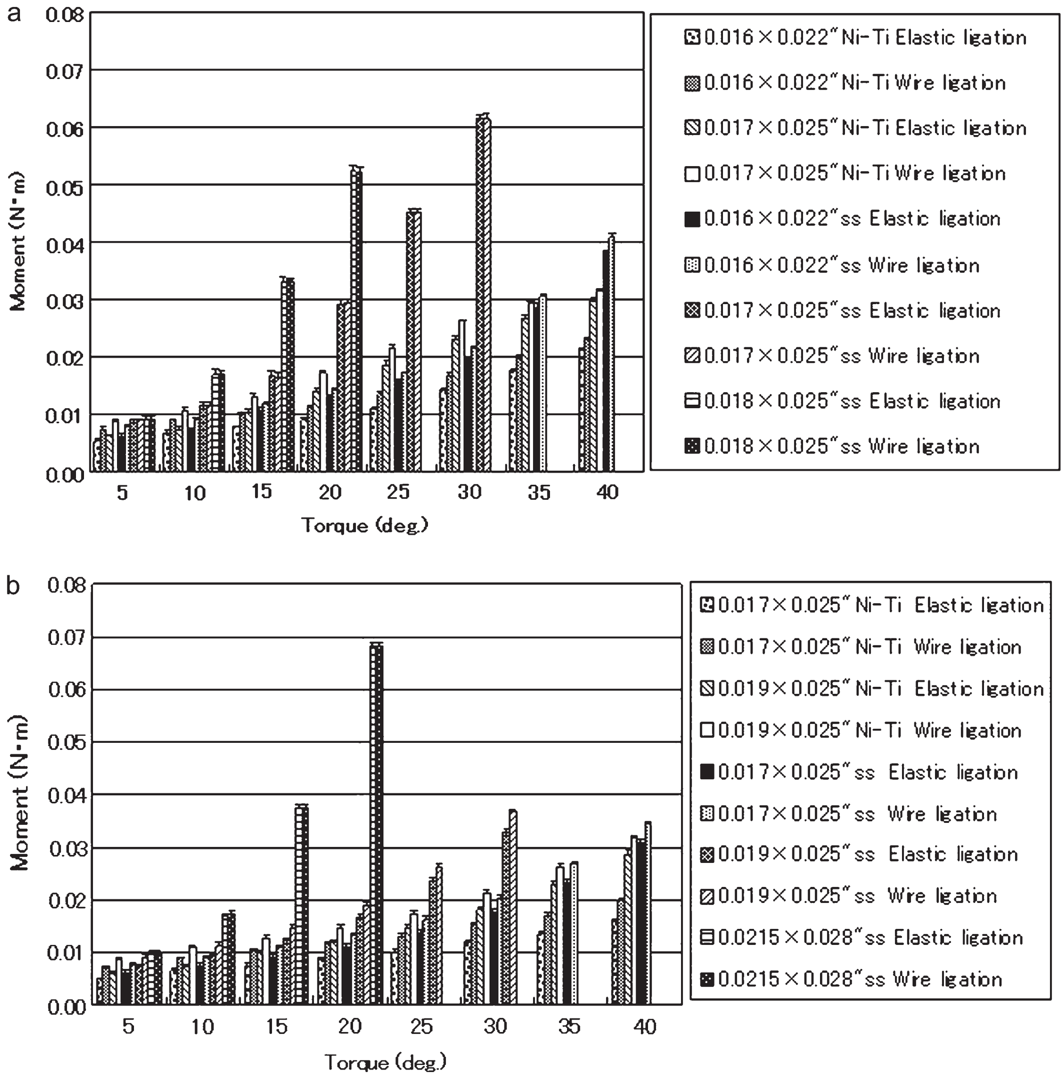

Figure 2 The torque moment of stainless steel (SS) and nickel–titanium (Ni-Ti) wires in (a) the 0.018 and (b) the 0.022 inch slot brackets.

at 15–40 degrees of applied torque, the moment of the SS wires was approximately 1.2–1.8 times larger than that of the Ni-Ti wires. The moment of the 0.017 × 0.025 inch SS wires ligated with elastics was significantly larger than that of the Ni-Ti wire at all applied torques, while that of the 0.017 × 0.025 inch SS wire ligated with elastics was approximately 1.5–2.7 times larger than the Ni-Ti wires. There was no significant difference between the 0.017 × 0.025 inch ligated SS and Ni-Ti wires at 5 degrees torque. At 10–20 degrees torque, the moment of the 0.017 × 0.025 inch SS wires ligated with wire was approximately 1.1–1.7 times larger than that of the Ni-Ti wires, and the moment was approximately 2.1–2.3 times larger than the Ni-Ti wires at 25 and 30 degrees.

Comparison between SS and Ni-Ti wire in 0.022 inch slot brackets

The moment of the 0.017 × 0.025 inch SS wires ligated with elastics was significantly larger than Ni-Ti wires at 5–40 degrees but not at 10 degrees, and the moment of SS wires was approximately 1.2–1.9 times larger than the Ni-Ti wires (Figure 2b, Tables 1 and 2). For the 0.017 × 0.025 inch wires with wire ligation, there was no significant difference between the moments of SS and Ni-Ti wires at 5–15 degrees torque. At 20–40 degrees, the moment of the 0.017 × 0.025 inch SS wires was approximately 1.1–1.7 times larger than Ni-Ti wires with wire ligation. The moment of the 0.019 × 0.025 inch wires ligated with elastics was also significantly larger than the Ni-Ti wires. The moment was approximately 1.2–1.8 times larger than Ni-Ti wires at 5–30 degrees torque. With the 0.019 × 0.025 inch wires with wire ligation, there was no significant difference in the moment between SS and Ni-Ti wires at 5 and 10 degrees torque. However, the moment of SS wires with wire ligation was approximately 1.1–1.7 times larger than that of Ni-Ti wires, and there were significant differences in the moment between SS and Ni-Ti wires at 15–30 degrees torque.

Table 1 The mean and standard deviation (SD) torque moment values for the 0.018 and 0.022 inch slot.

	Degrees		5		10		15		20		25		30		35		40	
	Wire size and materials	Ligation	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
0.018 inch slot	0.016 × 0.022 inch Ni-Ti	Elastic	54.6	3.0	67.6	5.3	78.1	1.3	91.0	2.9	110.4	2.2	142.4	2.1	177.1	3.4	212.1	3.9
		Wire	73.7	3.9	91.0	2.0	100.4	3.3	113.5	3.8	136.4	3.3	166.9	4.8	197.2	4.1	229.3	4.1
	0.016 × 0.022 inch SS	Elastic	61.8	4.5	73.0	3.6	107.6	5.9	130.6	2.7	159.2	1.9	198.1	2.3	283.1	9.4	382.2	2.3
		Wire	80.0	2.2	92.6	1.9	118.0	5.0	142.0	2.1	171.9	2.7	214.7	3.9	305.6	2.4	407.6	7.1
	0.017 × 0.025 inch Ni-Ti	Elastic	62.5	1.0	73.5	1.2	104.7	4.8	140.3	8.2	186.3	6.7	231.8	7.2	267.8	4.1	297.3.9	2.9
		Wire	88.7	4.3	105.0	5.8	132.3	4.8	172.3	4.2	214.7	6.1	262.7	2.7	294.1	3.4	315.3	4.5
	0.017 × 0.025 inch SS	Elastic	91.2	2.2	115.2	6.5	167.2	8.3	291.3	7.1	453.3	4.2	616.7	6.1	—	—	—	—
		Wire	91.1	2.5	117.7	4.8	166.0	7.4	294.3	6.5	452.9	5.9	615.0	9.5	—	—	—	—
	0.018 × 0.025 inch SS	Elastic	91.4	7.5	168.8	9.2	331.1	8.7	524.0	9.3	—	—	—	—	—	—	—	—
		Wire	90.6	6.0	169.5	6.0	331.7	6.9	521.5	7.3	—	—	—	—	—	—	—	—
0.022 inch slot	0.017 × 0.025 inch Ni-Ti	Elastic	50.6	1.9	65.6	7.0	74.7	6.7	86.7	4.3	101.4	6.4	120.0	3.0	135.5	3.6	159.5	4.2
		Wire	71.1	2.4	90.8	2.1	103.1	5.8	116.4	4.4	130.5	5.8	153.0	4.3	170.5	4.6	198.5	4.4
	0.017 × 0.025 inch SS	Elastic	62.4	4.1	74.4	5.8	90.1	5.1	109.4	5.7	136.8	4.6	176.1	5.6	231.2	6.5	307.2	9.2
		Wire	78.0	3.1	90.0	4.0	109.0	5.3	132.5	5.8	162.9	6.2	204.6	5.8	269.5	5.0	344.8	4.0
	0.019 × 0.025 inch Ni-Ti	Elastic	60.6	3.3	73.1	3.6	100.3	4.1	119.7	5.2	147.0	6.1	182.4	6.4	230.7	5.4	286.1	7.9
		Wire	88.7	3.5	109.5	4.1	128.7	4.2	148.1	4.3	174.6	6.0	214.9	5.3	263.6	5.2	318.0	5.0
	0.019 × 0.025 inch SS	Elastic	73.4	5.3	93.4	5.2	121.6	7.4	168.5	5.0	236.3	6.0	330.7	5.0	—	—	—	—
		Wire	89.3	6.7	113.0	7.0	145.0	6.1	190.0	5.4	263.1	5.9	367.6	5.2	—	—	—	—
	0.0215 × 0.028 inch SS	Elastic	99.4	3.8	170.6	3.9	376.7	5.4	682.5	5.1	—	—	—	—	—	—	—	—
		Wire	97.6	5.4	172.9	7.2	375.4	6.3	682.4	5.7	—	—	—	—	—	—	—	—

Unit: Nm × 10^{-4}.

Table 2 Comparison of statistical analysis of torque moment between stainless steel and nickel–titanium wires.

Bracket size	Wire size and ligation	Degrees							
		5	10	15	20	25	30	35	40
0.018 inch slot	0.016 × 0.022 inch elastic	NS	NS	**	**	**	**	**	**
	0.017 × 0.025 inch elastic	**	**	**	**	**	**		
	0.016 × 0.022 inch wire	NS	NS	**	**	**	**	**	**
	0.017 × 0.025 inch wire	NS	**	**	**	**	**		
0.022 inch slot	0.017 × 0.025 inch elastic	**	NS	**	**	**	**	**	**
	0.019 × 0.025 inch elastic	**	**	**	**	**	**		
	0.017 × 0.025 inch wire	NS	NS	NS	**	**	**	**	**
	0.019 × 0.025 inch wire	NS	NS	**	**	**	**		

NS, not significant. ***P* < 0.01.

Table 3 Statistical analysis of the torque moment between wire and elastic ligation.

Bracket	Wire size and material	Significance
0.018 inch slot	0.016 × 0.022 inch Ni-Ti	**
	0.017 × 0.025 inch Ni-Ti	**
	0.016 × 0.022 inch SS	**
	0.017 × 0.025 inch SS	NS
	0.018 × 0.025 inch SS	NS
0.022 inch slot	0.017 × 0.025 inch Ni-Ti	**
	0.019 × 0.025 inch Ni-Ti	**
	0.017 × 0.025 inch SS	**
	0.019 × 0.025 inch SS	**
	0.0215 × 0.028 inch SS	NS

NS, not significant. ***P* <0.01.

Comparison between wire and elastic ligation in 0.018 inch slot brackets

For the 0.016 × 0.022 inch Ni-Ti, 0.016 × 0.022 inch SS, and 0.017 × 0.025 inch Ni-Ti wires, the moments with wire ligation were significantly larger than those with elastic ligation (Figure 2a, Tables 1 and 3). The moments with wire ligation in the 0.016 × 0.022 inch Ni-Ti and SS wires were approximately 1.1–1.3 times larger than those with elastic ligation at 5–40 degrees torque. The moment of the 0.017 × 0.025 inch Ni-Ti wires with wire ligation was approximately 1.1–1.4 times larger than that with elastic ligation at 5–40 degrees torque. However, there were no significant differences in the moments between wire and elastic ligation with the 0.017 × 0.025 and 0.018 × 0.025 inch SS wires.

Comparison between wire and elastic ligation in 0.022 inch slot brackets

For the 0.017 × 0.025 and 0.019 × 0.025 inch wires, the moment with wire ligation was significantly larger than with elastic ligation (Figure 2b, Tables 1 and 3). The moment of the 0.017 × 0.025 inch Ni-Ti wires ligated with wire was approximately 1.2–1.4 times larger than that with elastic ligation at 5–40 degrees torque. The moment of the 0.017 × 0.025 inch SS wires with wire ligation was also 1.2–1.3 times larger than with elastic ligation at 5–35 degrees torque, while the moment was almost the same as that with elastic ligation at 40 degrees torque. With the 0.019 × 0.025 inch Ni-Ti wires, the moment with wire ligation was 1.5 times larger than with elastic ligation at 5 and 10 degrees torque and was 1.1–1.3 times larger at 15–40 degrees torque. For the 0.019 × 0.025 inch wires, the moment with wire ligation was 1.2 times larger than with elastic ligation at 5–15 degrees torque and was 1.1 times larger at 20–30 degrees torque. There was no significant difference in the torque moment of the 0.0215 × 0.028 inch SS wires between the moments with elastic and wire ligation.

Discussion

Comparison between SS and Ni-Ti alloy wire has previously been reported (Jarabak and Fizzell, 1972; Proffit, 2007). In this study, torque moments of SS wires were significantly larger than those of Ni-Ti wires under all conditions using the different slot and wire sizes. The torque moment of SS wires was approximately 1.5 times larger than that of Ni-Ti wires when the wire torque was applied at 15–20 degrees in the 0.018 inch slot brackets and 25 degrees in the 0.022 inch slot brackets. Comparing orthodontic forces with wire and elastic ligation, most of the torque moments with wire ligation were significantly larger than with elastic ligation. These results are consistent with previous studies (Rock and Wilson, 1989; Taloumis *et al.*, 1997). The moment with wire ligation was approximately 1.1–1.5 times larger than with elastic ligation; however, for the moment of the full slot size wire such as the 0.018 × 0.025 inch in the 0.018 inch slot brackets and the 0.0215 × 0.028 inch in the 0.022 inch slot brackets, there was no difference in moment between elastic and wire ligations. These findings might be useful for understanding the full effect of placing third-order bends in an archwire, and by extension, the effect of the archwire in producing desired tooth movement.

The force value of β-titanium (titanium–molybdenum: Ti-Mo) alloy wires has been reported to be around 40 per cent of that of SS but still twice that of Ni-Ti (Kapila and Sachdeva, 1989). These wires deliver approximately half the amount of force compared with SS (Burstone and Goldberg, 1980) or cobalt–chrome (Co-Cr) alloy wires (Kapila and Sachdeva, 1989) of comparable cross-sections and equal amounts of activation. A recent experimental study that evaluated β-titanium alloy wire demonstrated the intrusive forces and buccolingual torquing moments generated during anterior maxillary intrusion using different maxillary incisor intrusion mechanics (Sifakakis *et al.*, 2010). Those authors compared utility arch wires made of Co-Cr and Ti-Mo. The utility Co-Cr 0.016 × 0.016 inch wire exerted 8 per cent more intrusive force relative than the Ti-Mo alloy 0.017 × 0.025 inch utility archwire (Sifakakis *et al.*, 2010). Therefore, according to these previous results, the torque moment of β-Ti wire can be between SS and Ni-Ti and may be lower than SS but higher than Ni-Ti.

The lost motion between the wire and bracket is important for third-order bending (Andreasen, 1957; Andreasen and Quevedo, 1970). The present results at 20 degrees with wire ligation showed that the moment of the 0.016 × 0.022 inch SS wires in 0.018 inch slot brackets was decreased approximately 70 per cent compared with 0.018 × 0.025 inch SS wires, and the moment of the 0.017 × 0.025 inch SS wires was decreased approximately 40 per cent compared with the 0.018 × 0.025 inch SS wires. In the 0.022 inch slot brackets with wire ligation, the moment of the 0.017 × 0.025 inch SS wires decreased approximately 80 per cent and with the 0.019 × 0.025 inch SS wires decreased 70 per cent compared with the 0.0215 × 0.028 inch SS wires at 20 degrees.

Reitan (1957, 1985) suggested that a torquing movement performed with a 0.021 × 0.025 inch edgewise arch exerting a force at the root apex of about 130 g could produces histologic changes without any hyalinized areas. The average upper incisor root length is 13.0 mm (Ash and Nelson, 2003). Thus, it was hypothesized that the optimum torque was approximately 0.01–0.02 Nm, which was basically calculated by data from previous studies (Burstone *et al.*, 1961; Burstone, 1966, 1994; Martuccio, 1969; Wainwright, 1973; Lee, 1995a,b, 1996). Concerning the active moment of optimum torques of the 0.016 × 0.022 inch Ni-Ti wires in 0.018 inch slot brackets, the hypothesized optimum torques with elastic ligation was 22 degrees and with wire ligation 13 degrees. For the 0.016 × 0.022 inch SS wires, the torques with elastic and wire ligation were at 14 and 12 degrees, respectively. For the 0.017 × 0.025 inch Ni-Ti wires, the hypothesized optimum torques were 14 degrees with elastic ligation and 10 degrees with wire ligation. Torque of the 0.017 × 0.025 inch SS wires was observed at 7 degrees and of the 0.018 × 0.025 inch SS wires at 6 degrees for both ligations.

In the 0.022 inch slot brackets, the hypothesized optimum torque of the 0.017 × 0.025 inch Ni-Ti wires with elastic ligation was 24 degrees, and the moment with wire ligation was 13 degrees. For the 0.017 × 0.025 inch SS wires, the torque of elastic ligation was determined at 17 degrees and wire ligation at 12 degrees. For the 0.019 × 0.025 inch Ni-Ti wires, torques with elastic and wire ligations were 14 and 7 degrees, respectively. For the 0.019 × 0.025 inch SS wires, the torques with elastic and wire ligations were 11 and 7 degrees, respectively. The hypothesized optimum torque moment of the 0.0215 × 0.028 inch SS wires could be at 5 degrees in both elastic and wire ligations.

The identification of these wire–bracket–ligation combinations could lead to shorter treatment times. Ricketts (1979) suggested that the physiological process of resorption by osteoclastic cells is the basic activity that allows bone changes and tooth movement. Thus, the hypothesized optimum torque moment produced by this effective combination may prevent treatment side effects such as root and bone resorption. Studying toque moments should involve more accurate simulation of loading and approximation of material behaviour as well as variations in the geometries of the periodontal tissue, bone, and tooth shapes, including tooth contact. The results of the preset study demonstrate the most useful combinations to generate the maximum torque moment between the wire–bracket–ligation system for archwire size and materials.

Conclusions

Torque moment was increased with larger degrees of torque and wire sizes. There was no significant difference in torque moment between the SS and Ni-Ti wires at lower degrees of torque and at torque higher than 40 degrees. The torque moment with wire ligation was significantly larger than with elastic ligation for the 0.016 × 0.022 and 0.017 × 0.025 inch Ni-Ti wires in the 0.018 inch slot brackets and the 0.017 × 0.025 and 0.019 × 0.025 inch SS and Ni-Ti wires in the 0.022 inch slot brackets. However, there was no significant difference in torque moment between either ligation when using the full slot size wires.

A limitation of this study was that the torque moment was measured under dry conditions. Although there may be some discrepancies between *in vitro* and *in vivo* studies, these results can help in understanding the amount of third-order bends for wire–bracket–ligation combinations.

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