

Force systems yielded by different designs of T-loop

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Objectives: To determine the mechanical characteristics of beta-titanium T-loops with and without helices, with 0 and 180 degree gable bends and constructed from 0.017 inch x 0.025 inch and 0.019 inch x 0.025 inch wire.

Methods: Forty beta-titanium T-loops were centrally positioned in a universal testing machine. The horizontal force and the moment/force ratios during activation were recorded at 1 mm intervals, up to a maximum of 7 mm. The data were analysed with analysis of variance complemented by the Tukey test for multiple comparisons.

Results: The results demonstrated that the transverse section of the wire had the greatest effect on the horizontal force produced by the loops. Significantly lower levels of horizontal force were obtained with loops made with the smaller 0.017 inch x 0.025 inch wire. Loops with gable bends yielded high moment/force ratios, whereas loops without gable bends had low moment/force ratios. In general, T-loops with helices yielded lower magnitudes of horizontal force and moment/force ratios than plain T-loops.

Conclusions: The horizontal forces and moment/force ratios generated by plain T-loops with 180 degree gable bends yielded more adequate force systems. Incorporation of helices in the design of T-loops seems to be unnecessary. (Aust Orthod J 2005; 21: 103–110)

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Introduction

During orthodontic space closure the optimum response, both clinically and histologically, is more likely to occur when precisely calibrated force systems are used. Loops incorporated into either continuous or segmented archwires can be designed to deliver known forces so that pure translation and frictionless space closure occur.^{1,2} The segmented arch technique, which uses a variety of prefabricated and precalibrated orthodontic loops, is able to deliver precise and carefully controlled forces.^{1–3} Attempts to improve the force systems produced by this appliance have resulted in a number of different T-loop designs.^{4–6} Sectional loops can be used to retract the canines and/or the anterior segment, to protract the posterior segment, or to retract and protract teeth at the same time.⁷

Control of the force systems applied to the teeth is one of the main challenges in orthodontic biomechanics.

Unfortunately, it has proved extremely difficult to obtain an optimal force and M/F ratio capable of pure translation together.⁸ Several investigations have been conducted with a view to designing beta-titanium T-loops with predictable mechanical behaviour and compatible with the biological processes responsible for tooth movement.^{4,8–13}

The purpose of this study is to determine the mechanical characteristics of centred beta-titanium T-loops with and without helices, with 0 degree and 180 degree gable bends and constructed from 0.017 inch x 0.025 inch and 0.019 inch x 0.025 inch wire.

Material and methods

The present study used 40 space closing loops fabricated by a single operator from 0.017 inch x 0.025 inch and 0.019 inch x 0.025 inch beta-titanium wires (TMA,Ormco, USA). The specimens were divided into two groups: plain T-loops (T1) and T-loops with

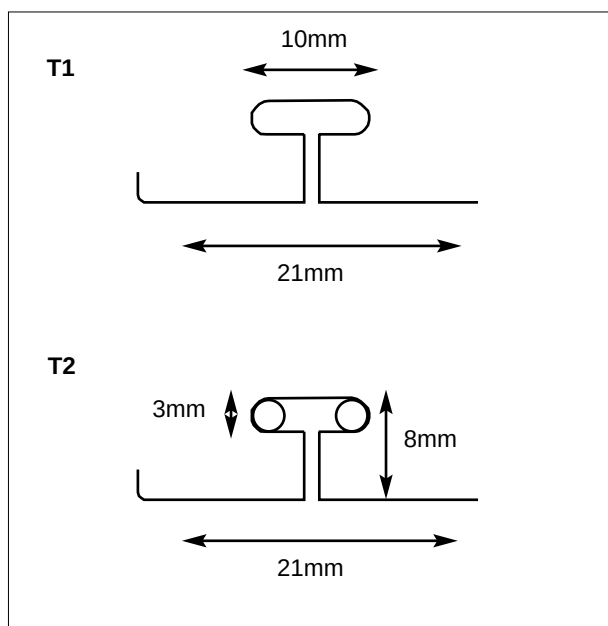


Figure 1. Design of T-loops (T1) and T-loops with helices (T2), and their respective dimensions.

Table I. Experimental design.

Group	loop (N = 20)	Transverse section (N = 10)	Gable bend (degrees) (N = 5)
T1	Plain T-loop	0.017" x 0.025"	0
			180
		0.019" x 0.025"	0
			180
T2	T-loop with helices	0.017" x 0.025"	0
			180
		0.019" x 0.025"	0
			180

two apical helices (T2). All loops were 8 mm in height (Figure 1). There were 20 specimens in each group. Half of the specimens in each group were made from 0.017 inch x 0.025 inch wire, and the other half were made from 0.019 inch x 0.025 inch wire. Five of these loops had no gable bends and five loops had 180 degree gable bends (Table I).

The anterior (alpha) and posterior (beta) ends of each closing loop were 15.5 mm and 13.5 mm respectively. A 2 mm right angle bend was placed in the alpha end of each spring to prevent the wire sliding in

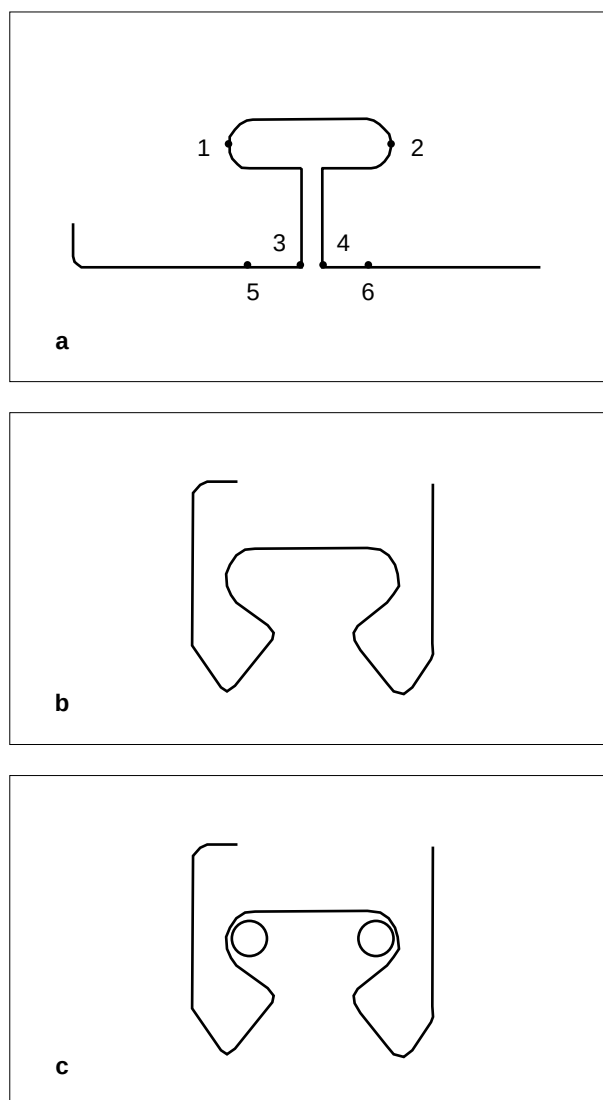


Figure 2. a: Points for insertion of gable bends in the T1 and T2 loops. b: Plain T-loop with 180 degrees gable bend. c: T-loop with helices with 180 degrees gable bend.

the slot, which could lead to errors during loading of the specimens. The alpha ends of the springs were then tied in a 0.022 inch x 0.028 inch twin stainless steel canine bracket (Dyna-lock, 3M Unitek, USA) with 0 degree torque and angulation attached to the load cell of the universal testing machine. During testing each end was 10.5 mm in length, and each loop was centrally placed between the load cell and moment transducer of the universal testing machine.

Gable bends were placed in the loops as follows: 40 degree bends were placed at positions 1 and 2, 25

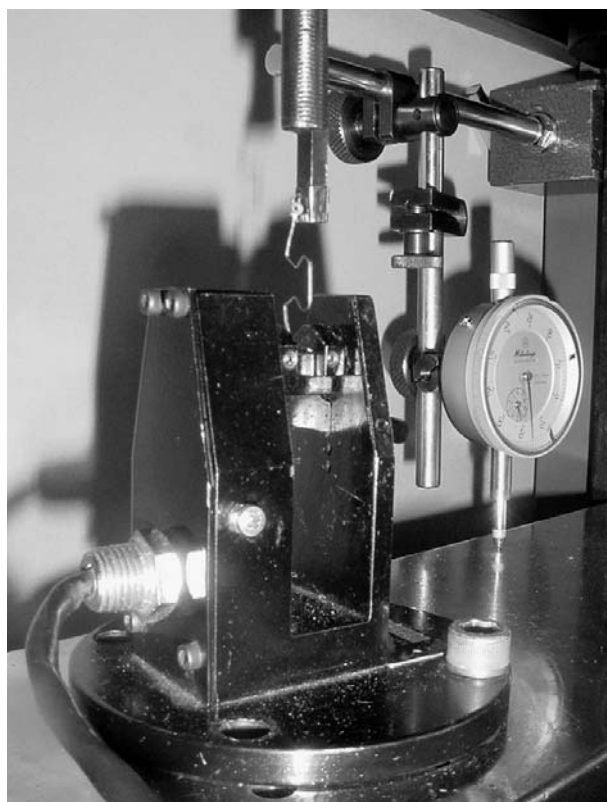


Figure 3. Mechanical testing of the specimens. The moment transducer, vertical rod for activating the specimens and dial gauge for measuring extension are shown.

degree bends were placed at positions 3 and 4, and 25 degree bends were placed at positions 5 and 6 (3 mm from the base of the 'T'). These bends resulted in a total activation of 180 degrees (Figure 2).¹³ To ensure that the shape and dimensions of the loops and gable bends were standardised the specimens were compared to templates drawn on millimetre paper.

Mechanical testing was performed in an Instron universal testing machine (Model TTDML, Instron Inc., MA, USA) fitted with a moment transducer (Transducer Ltda., São Paulo, Brazil), a digital indicator to measure extension (Model TMDE, Transducer (Transducer Ltda., São Paulo, Brazil), and a dial micrometer (Mitutoyo Corporation, Tokyo, Japan) with a range of $10\text{mm} \pm 0.01\text{ mm}$. The latter was used to measure the amount of activation. The digital indicator, set at 5V of excitation and 5 mV/V of sensitivity, attached to the calibrated moment transducer measured the moments generated.

Because each loop was symmetrically positioned in a 21 mm space during testing, similar horizontal

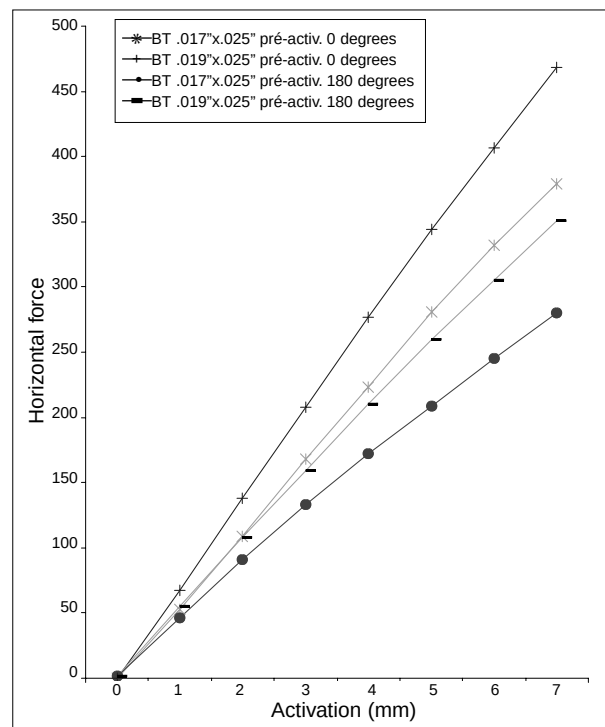


Figure 4. Mean magnitudes of horizontal force (g) generated by the T-loops fabricated according to the interactions between transverse section (.017"x.025" and .019"x.025") and gable bends (0 degrees and 180 degrees).

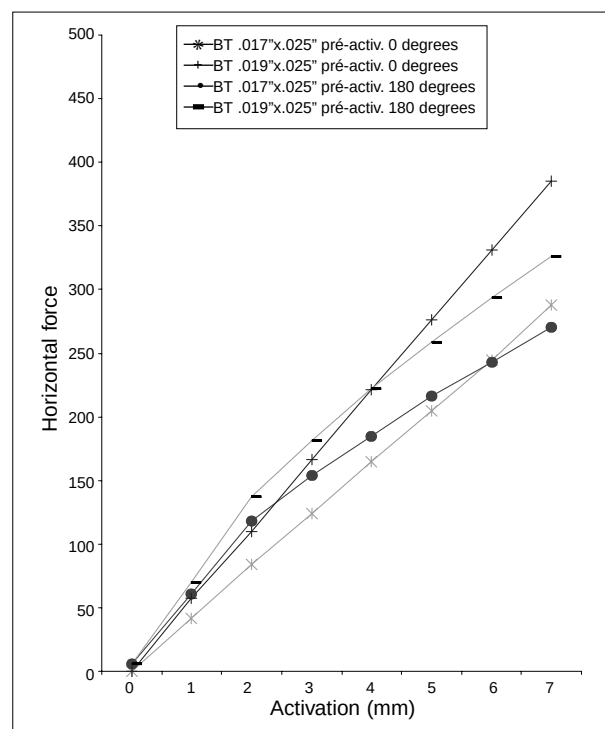


Figure 5. Mean magnitudes of horizontal force (g) generated by the T-loops with helices fabricated according to the interactions between transverse section (.017"x.025" and .019"x.025") and gable bends (0 degrees and 180 degrees).

Table II. Horizontal forces, in grams, generated by plain T-loops during activation.

Acti- vation (mm)	Transverse section	Gable bend			
		0 degree		180 degrees	
		Mean	SD	Mean	SD
0	0.017" x 0.025"	0.00	0.00	6.00	2.24
	0.019" x 0.025"	0.00	0.00	6.00	2.24
		B		A	
1	0.017" x 0.025"	53.00	2.74	46.00	8.94 b
	0.019" x 0.025"	67.00	8.37	55.00	15.41 a
		B		A	
2	0.017" x 0.025"	109.00	6.52	91.00	9.62 b
	0.019" x 0.025"	138.00	14.83	108.00	17.54 a
		B		A	
3	0.017" x 0.025"	168.00	12.04	133.00	10.37 b
	0.019" x 0.025"	208.00	20.49	159.00	21.04 a
		B		A	
4	0.017" x 0.025"	223.00	12.55	172.00	13.51 b
	0.019" x 0.025"	277.00	25.88	210.00	21.21 a
		B		A	
5	0.017" x 0.025"	281.00	17.10	209.00	15.57 b
	0.019" x 0.025"	344.00	29.66	260.00	23.18 a
		B		A	
6	0.017" x 0.025"	332.00	18.23	245.00	15.81 b
	0.019" x 0.025"	407.00	34.39	305.00	23.72 a
		B		A	
7	0.017" x 0.025"	379.00	18.51	280.00	15.81 b
	0.019" x 0.025"	468.00	38.01	351.00	24.60 a
		B		A	

The means followed by letters are different at the 5 per cent level of significance (ANOVA and Tukey for multiple comparisons).

forces and moments occurred both ends of each loop (Figure 3).^{3-4,11-15} All specimens were extended up to 7 mm. Testing was interrupted at 1 mm intervals and the amount of force and tensile moment recorded. The M/F ratios generated during loading of each loop were calculated from this data. The data were analysed with the analysis of variance, complemented by the Tukey test for multiple comparisons. The five per cent level of significance was used in both tests.

Results

The means and standard deviations of the horizontal forces produced by plain T-loops are given in Table II and Figure 4. Higher horizontal forces were yielded by T-loops made from the thicker 0.019 inch x 0.025 inch wire than the 0.017 inch x 0.025 inch wire. The

Table III. Horizontal forces, in grams, generated by T-loops with helices during activation.

Acti- vation (mm)	Transverse section	Gable bend			
		0 degree		180 degrees	
		Mean	SD	Mean	SD
0	0.017" x 0.025"	0.00	0.00	6.00	2.24
	0.019" x 0.025"	0.00	0.00	6.00	2.24
		B		A	
1	0.017" x 0.025"	42.00	2.74	61.00	5.48 b
	0.019" x 0.025"	57.00	5.70	70.00	3.54 a
		B		A	
2	0.017" x 0.025"	84.00	7.42	118.00	18.23 b
	0.019" x 0.025"	110.00	10.61	137.00	9.75 a
		B		A	
3	0.017" x 0.025"	124.00	7.42	154.00	18.84 b
	0.019" x 0.025"	166.00	12.45	181.00	11.40 a
		B		A	
4	0.017" x 0.025"	165.00	9.35	185.00	21.51 b
	0.019" x 0.025"	221.00	17.10	222.00	16.81 a
		B		A	
5	0.017" x 0.025"	205.00	12.75	216.00	19.81 b
	0.019" x 0.025"	276.00	20.12	259.00	18.51 a
		B		A	
6	0.017" x 0.025"	245.00	16.96	243.00	22.53 b
	0.019" x 0.025"	331.00	23.02	294.00	19.49 a
		B		A	
7	0.017" x 0.025"	288.00	19.24	270.00	22.64 b
	0.019" x 0.025"	385.00	27.16	326.00	24.08 a
		B		A	

The means followed by letters are different at the 5 per cent level of significance (ANOVA and Tukey for multiple comparisons).

insertion of gable bends led to lower horizontal forces compared with loops without gable bends.

The means and standard deviations for the horizontal forces produced by the T-loops with helices are given in Table III and Figure 5. In general, the horizontal forces yielded by these T-loops were also influenced by the transverse section of the wire: higher horizontal forces were recorded from the springs made from the thicker 0.019 inch x 0.025 inch wire. The insertion of gable bends had a variable effect on the horizontal forces.

The M/F ratios produced by the plain T-loops and the T-loops with helices are given in Tables IV and V and Figures 6 and 7. In general, the M/F ratios yielded by these loops were more influenced by the insertion of gable bends. Without 180 degree gable

Table IV. Moment/force ratios, in millimetres, generated by plain T-loops during activation.

Acti- vation (mm)	Transverse section	Gable bend			
		0 degree		180 degrees	
		Mean	SD	Mean	SD
0	0.017" x 0.025"	0.00	0.00	248.00	73.39
	0.019" x 0.025"	0.00	0.00	279.20	115.28
		B		A	
1	0.017" x 0.025"	2.34	0.20	33.21	7.81
	0.019" x 0.025"	2.92	0.44	40.96	9.61
		B		A	
2	0.017" x 0.025"	2.20	0.22	17.53	2.96 b
	0.019" x 0.025"	2.72	0.10	21.33	3.44 a
		B		A	
3	0.017" x 0.025"	2.17	0.20	12.50	1.88 b
	0.019" x 0.025"	2.62	0.17	14.95	2.06 a
		B		A	
4	0.017" x 0.025"	2.20	0.14	9.93	1.41 b
	0.019" x 0.025"	2.52	0.19	11.54	1.30 a
		B		A	
5	0.017" x 0.025"	2.11	0.12	8.29	1.14 b
	0.019" x 0.025"	2.45	0.17	9.40	0.98 a
		B		A	
6	0.017" x 0.025"	2.04	0.12	7.08	0.90 b
	0.019" x 0.025"	2.37	0.14	8.02	0.73 a
		B		A	
7	0.017" x 0.025"	1.98	0.11	6.17	0.70 b
	0.019" x 0.025"	2.30	0.13	6.92	0.56 a
		B		A	

The means followed by letters are different at the 5 per cent level of significance (ANOVA and Tukey for multiple comparisons).

Table V. Moment/force ratio, in millimetres, generated by the T-loops with helices during activation.

Acti- vation (mm)	Transverse section	Gable bend			
		0 degree		180 degrees	
		Mean	SD	Mean	SD
0	0.017" x 0.025"	0.00	0.00	197.40	54.58
	0.019" x 0.025"	0.00	0.00	252.80	66.12
		B		A	
1	0.017" x 0.025"	2.77	0.55	19.89	2.24 b
	0.019" x 0.025"	4.02	0.28	22.25	1.37 a
		B		A	
2	0.017" x 0.025"	2.52	0.30	11.15	1.16 b
	0.019" x 0.025"	3.57	0.36	12.31	0.83 a
		B		A	
3	0.017" x 0.025"	2.50	0.24	9.01	0.75 b
	0.019" x 0.025"	3.27	0.32	9.92	0.75 a
		B		A	
4	0.017" x 0.025"	2.58	0.17	7.83	0.76 b
	0.019" x 0.025"	3.20	0.33	8.52	0.82 a
		B		A	
5	0.017" x 0.025"	2.62	0.17	6.87	0.64 b
	0.019" x 0.025"	3.13	0.29	7.55	0.74 a
		B		A	
6	0.017" x 0.025"	2.58	0.15	6.25	0.59 b
	0.019" x 0.025"	3.01	0.30	6.82	0.70 a
		B		A	
7	0.017" x 0.025"	2.51	0.18	5.70	0.56 b
	0.019" x 0.025"	2.88	0.27	6.27	0.70 a
		B		A	

The means followed by letters are different at the 5 per cent level of significance (ANOVA and Tukey for multiple comparisons).

bends, both the plain T-loops and the T-loops with helices yielded low M/F ratios. With gable bends the loops gave higher M/F ratios. Both types of loop produced higher M/F ratios when the thicker 0.019 inch x 0.025 inch wire was used.

Discussion

The biomechanical performance of closing T-loops has been the subject of many investigations, but so far no single design has been able to deliver the ideal combination of a light force and a M/F ratio of 10:1 over the full range of activation. We found loops fabricated from 0.017 inch x 0.025 inch beta titanium wire yielded force levels nearly 20 per cent lower than loops fabricated from 0.019 inch x 0.025 inch wire. On the other hand, the transverse section of

the wire used had little influence on the M/F ratio: as the moment increased with the thicker wire the horizontal force increased more-or-less proportionately.

Gable bends generally increased the horizontal force yielded by T-loops with helices, and lowered it when incorporated in plain T-loops. This may be explained by the fact that the neutral position is difficult to achieve.^{3,8,16} Gable bends deform a loop so that when the ends are engaged in the brackets there is a residual horizontal force before any activation is placed. A loop centrally placed and, therefore, in the neutral position generates moments, but not a residual horizontal force, when the ends are engaged.¹⁷ Even though the gable bends were evenly distributed through the loops occlusoapically, the inactivated loops still had a residual horizontal force.^{8,16,18}

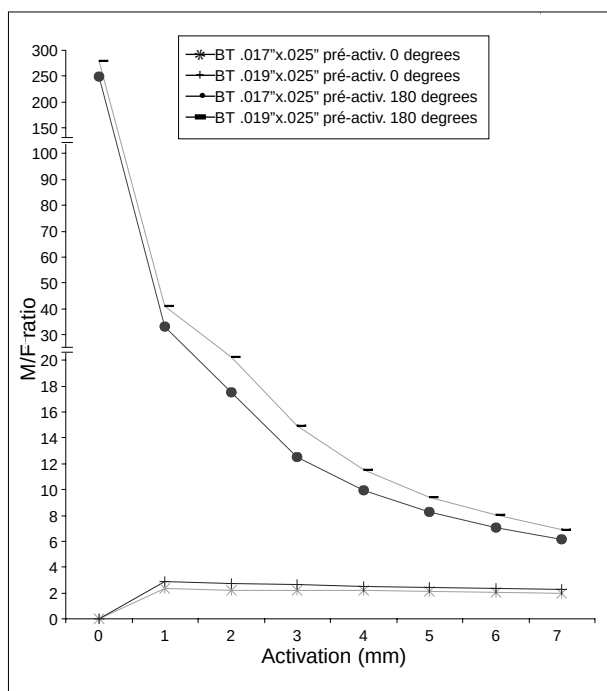


Figure 6. Mean magnitudes of moment/force ratio (mm) generated by the T-loops fabricated according to the interactions between transverse section (.017"x.025" and .019"x.025") and gable bends (0 degrees and 180 degrees).

However, these forces were quite low and may not be of clinical significance (Figures 4 and 5).

The height of a T-loop also affects both the horizontal force and M/F ratio. Others have reported that when the height of a closing loop was increased from 7 mm to 8.5 mm the horizontal force reduced and the M/F ratio increased.¹⁹ For these reasons we used 8 mm high loops. There seems little advantage in using loops made in NiTi or TMA as both materials did not produce the M/F ratio necessary for translational movement.²⁰ Although TMA T-loops yielded adequate horizontal force levels, NiTi T-loops produced forces that were too light for *en masse* retraction.

The M/F ratio is the relationship between the moment and the horizontal force.²¹ In the case of a medium-sized tooth with normal height of the alveolar bone crest uncontrolled tipping will occur with M/F ratios < 8; controlled tipping will occur when the M/F ratio = 8; translation will occur when the M/F = 10; and root correction will occur when the M/F ratio is ≥ 12. Insertion of gable bends in both types of T-loop (plain and with helices) yielded

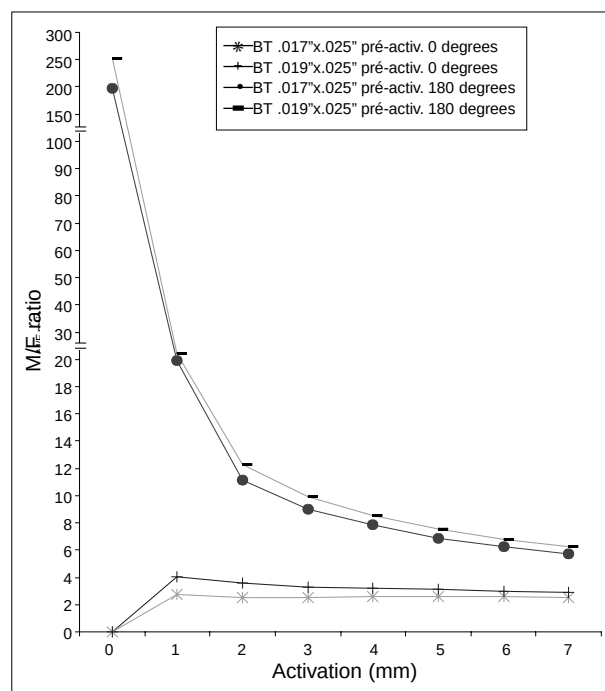


Figure 7. Mean magnitudes of moment/force ratio (mm) generated by the T-loops with helices fabricated according to the interactions between transverse section (.017"x.025" and .019"x.025") and gable bends (0 degrees and 180 degrees).

high M/F ratios (Figures 6 and 7). Thus, during deactivation the M/F ratios would, theoretically, carry out root correction, translation, controlled tipping and uncontrolled tipping. Without gable bends all loops produced M/F ratios normally associated with uncontrolled tipping (Figures 6 and 7).

The T-loops with helices generally yielded horizontal forces approximately 10 per cent lower than plain T-loops. We attribute this to the additional wire used in the helices, which also increases the elastic limit during activation. However, this difference was not as great as the 25 to 30 per cent difference when closing loops are made from stainless steel.²² The lesser reduction with beta-titanium closing loops with helices may be due to friction between the surfaces of the wire in contact in the helices. Incorporation of helices in the closing loops reduced the M/F ratios because the horizontal forces fell as the moments reduced. In summary, the force systems produced by these devices did not significantly benefit from the incorporation of helices as the horizontal forces produced by the T-loops were light and the M/F ratios low. Light forces have, however, been

recommended as they minimise tissue damage and discomfort to the patient.^{23–26}

The results of this study demonstrate that beta-titanium plain T-loops and T-loops with helices may produce low magnitudes of horizontal force, compatible with the values suggested in the literature for the movement of incisors and/or canines during orthodontic space closure.^{25,27–29} Furthermore, the M/F ratios produced by these loops (when gable bends were inserted) were high enough to achieve translation and root correction. To obtain the desired tooth movement the loops need to be reactivated a predetermined amount to obtain the appropriate horizontal force and M/F ratio.

Conclusions

1. Closing loops made 0.019 inch x 0.025 inch beta titanium wire gave higher horizontal forces than loops made from 0.017 inch x 0.025 beta titanium wire. The size of the wire had only a small effect on the M/F ratio generated.
2. The insertion of 180 degree gable bends in T-loops with and without helices increased the M/F ratio, but had a variable effect on the magnitude of the horizontal force.
3. In general, the beta-titanium T-loops without helices yielded higher magnitudes of horizontal force and M/F ratios than the beta-titanium T-loops with helices.
4. After insertion of gable bends, plain T-loops and T-loops with helices yielded high M/F ratios, whereas loops without gable bends generated low M/F ratios.
5. Concomitant analysis of the horizontal force and M/F ratio generated during activation of the loops showed that the T-loops without apical helices yielded more adequate force systems.

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